

# Transactions

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# TRANSACTIONS

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## Introduction to Report on Investigation of Physical Properties of Steel Foundry Sands at Elevated Temperatures

BY WERNER FINSTER\*, READING, PA.

Shortly after Mr. J. R. Young had completed his investigation on "The Effect of Ramming," published in the Third Progress Report on Investigation on Effect of High Temperature on Steel Sands, 1942, he was asked by the United States Navy to help as a full time instructor in the Navy's Engineering Training Program. Mr. Young accepted this call, and resigned as A.F.A. Research Fellow. Due to his resignation, the Research Program, under the direction of Subcommittee 6b7 on the Physical Properties of Steel Foundry Sands at Elevated Temperatures, had to be interrupted from September 1942 to March 1943, when the A.F.A. was very fortunate to engage Douglas C. Williams as A.F.A. Research Fellow. Mr. Williams, a graduate chemist, came to us from the Research Laboratory, American Steel Foundries, East Chicago, Ind. Both his technical training, and his knowledge of steel foundry sand problems, qualify Mr. Williams highly for his present duties as A.F.A. Research Fellow.

Prior to Mr. Williams' appointment, Subcommittee 6b7 had made arrangements with the Naval Research Laboratory, Anacostia Station, Washington, D. C., to collaborate in the Research Program by investigating some phases of the Basic Research program. Upon Mr. Williams' appointment, it became necessary to carry out a series of tests to check the reproductibility of test results between the A.F.A. Sand Research Laboratory, and the Naval Research Laboratory, before dividing the program between the two laboratories. In the Fourth Progress Report, Mr. Williams presents the results of this investigation.

An Appendix to the Fourth Progress Report contains information on High Temperature Sand Testing, which has been submitted to Committee 6b7 by members. This material does not carry the official approval of Subcommittee 6b7. It is included in the form of an Appendix, to stimulate interest in High Temperature work among the members of A.F.A.

In the Fall of 1943, Subcommittee 6b7 decided to expand its program at Cornell University. While the Basic Research investigation is being carried on, trend curves will be established on the influence of various binders on the

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NOTE: This report was presented at a session on Foundry Sand Development at the 48th Annual Meeting of A.F.A. in Buffalo, N. Y., Wednesday, April 26, 1944.

High Temperature Properties of Steel Foundry Sand mixtures. This work will be carried out on a commercial dilatometer. The Executive Committee of the A.F.A. has made funds available to engage additional help, and Harry W. Dietert, President, Harry W. Dietert Co., Detroit, has presented the A.F.A. with a dilatometer for this work.

Our knowledge of sand properties at high temperatures is still quite limited. As our work in this field progresses, we are learning that factors which are of minor importance in room temperature testing, greatly influence test results at high temperatures, and that much greater accuracy in testing equipment and technique is necessary to obtain reproducible data.

The finish of our castings, their freedom from sand defects and sand inclusions, is dependent on the behavior of the sand during pouring and solidification. Therefore, it is obvious that any knowledge of the properties of sands at high temperatures is of practical value. To pursue its work, the Subcommittee needs the wholehearted support of the members of the A.F.A., and their patient understanding that fundamental information must first be gained before practical application can be carried out intelligently.

As Chairman of Subcommittee 6b7, I wish to extend my sincere thanks to the members of this Committee for their excellent cooperation, to Dr. H. Ries, and Professor J. R. Moynihan, Cornell University, for their guiding interest and help in this work; to the officers and staff of the Naval Research Laboratory for their participation in the work, and to the Navy Department for sponsoring a Sand Research Program, which made this cooperation desirable and feasible.

## Fourth Progress Report on Investigation of Physical Properties of Steel Foundry Sands at Elevated Temperatures

BY D. C. WILLIAMS\*, ITHACA, N. Y.

### Abstract

*This report records the work done on the High Temperature Testing of Foundry Sands at Cornell University, Ithaca, N. Y., under the direction of Subcommittee 6b7, Foundry Sand Research Project, including the results of cooperative tests conducted between various laboratories to determine the hot compressive strength of molded sand test specimens.*

*The cooperative tests were first conducted between the Naval Research Laboratory, Washington, D. C., and Cornell University, Ithaca, N. Y. Later they were expanded to include two additional laboratories, namely, those of the H. W. Dietert Co., Detroit, Mich., and the Experimental Station, Hercules Powder Co., Wilmington, Del. As a result of the work conducted during the past year, improvements have been made in the testing equipment and in the art and science of high temperature foundry sand testing. Also the margin of error, for the mixtures tested in the cooperative work, has been decreased by standardizing equipment, procedures and testing technique within and between laboratories.*

*Discoveries made during the past year at the University have resulted in the following changes in the only available commercial testing equipment:*

(1) *An investigation of the size of the posts and the material from which they were made, as first used in the dilatometer, resulted in the manufacturer changing the diameter of the posts to  $1\frac{1}{8}$  in., and the use of a material known as "mullfrax-S" in the post.*

(2) *An investigation of air drafts through the heating unit resulted in the adoption of ways and means to practically eliminate air currents in the furnace.*

(3) *Improved positioning of test specimen within the furnace has been obtained through temperature traverses of the heating element.*

(4) *Numerous refinements in testing technique have been discovered, both at the University and through the cooperative tests, which have improved the ability to duplicate results within the apparatus.*

*From the past year's work, including the cooperative tests between laboratories, dilatometer operators should find their ability to duplicate test results improved if they will give consideration to the following items:*

(1) *Rammer mounted rigidly on a solid foundation.*

\*A.F.A. Research Fellow, Cornell University.

- (2) Use disks of the same dimensions and materials for all tests.
- (3) Assure that there is good contact between the disks and test specimen.
- (4) Keep the refractory posts rigid.
- (5) Use the same furnace temperature control setting recovery time for all tests.
- (6) Use the same exposure (soaking) time for all tests.
- (7) Use the same rate of loading for all hot compressive strength tests.\*
- (8) Keep the furnace heated continuously.
- (9) Keep the control thermocouple bead at the chosen location.
- (10) Use an overnight idling temperature control setting of 1150° F.

The following items referring to the test apparatus were found to have little or no effect on the variations in test results:

- (1) Type of electrical connections to the heating element.
- (2) Separate cooling of the heating element ends.

It also was found that specimen location within individual furnaces was not so important for routine testing, but comparable specimen locations were essential when results between laboratories were being compared. Further, it was found that, if the composition of the bentonite used in sand mixtures being tested changed, the hot compressive strength of the sand mixtures also changed.

1. The Subcommittee on the Physical Properties of Steel Foundry Sands at Elevated Temperatures, Foundry Sand Research Project, has under its direction a "basic research" program of investigation. The term "basic research" has been selected to describe a single-variable program to determine the effect of the following variables on the elevated temperature behavior of sand mixtures:

- (1) Grain size.
- (2) Moisture content of the sand mixture.
- (3) Time of temper (storage in a sealed container).
- (4) Time of mixing (muller type mixer).
- (5) Type of bonding material.
  - (a) bentonite
  - (b) fire clay
  - (c) organic
  - (d) inorganic
- (6) Silica flour.
- (7) Degree of ramming.

2. It is hoped that all but one of the variables can be held constant while investigating the effect of that one. As the investigation proceeds, the subcom-

\*It is essential, to maintain the same rate of loading for all tests, that the hydraulic system used to exert pressure on the specimens be kept free of air.

mittee aims to make available to foundrymen certain safe trends as they are determined. These trends will concern the hot compressive strength and the linear expansion of various sand mixtures as determined from molded test specimens.

#### *Approach to the Problem*

3. The above research investigation is being carried on primarily at Cornell University, Ithaca, N. Y. Its aim is to establish not only the "how" and "why" of high temperature sand testing but also the behavior of foundry sand at those temperatures. The former involves not only a study of the means for conducting the tests but also the manner in which the tests should be conducted to secure the best possible results and the correct interpretation of those results.

4. The latter, the behavior of foundry sands at elevated temperatures, obviously can be determined intelligently only when the former, the "how" and "why" of high temperature sand testing, is known.

5. From this, it can be seen easily that there is considerable difference between the research and routine approach to the problem. Research is interested in fundamentals, routine testing only in the results obtained. The interpretation of data in manufacture of castings is of paramount importance to both. Therefore, each assists the other during the development stage of any test.

#### *Beginning of Cooperative Work*

6. The investigation outlined previously is a large one, involving thousands of determinations. Therefore, to hasten the results obtained from the "basic research" program, advantage was taken of an offer by the Naval Research Laboratory, Washington, D. C., to assist in the investigation and a cooperative project, involving the two laboratories, for the purpose of dividing the work, was undertaken. The first step was to standardize techniques and testing equipment in the two laboratories. Each laboratory was to have been able to duplicate the other's work before continuing on separate parts of the single-variable program.

7. To determine how closely the two laboratories checked, and for the purpose of finding differences in equipment and technique, a preliminary check between the two laboratories was conducted.

8. Two mixtures were prepared at the Naval Research Laboratory, one containing 4 and the other 10 per cent bentonite and a portion of each shipped to the University. On the same day, both laboratories made the same room and high temperature tests.

9. Results of the first check tests indicated good agreement between the room temperature tests and on the high temperature expansion and contraction tests for both mixtures. On the hot strength test, fair agreement was obtained on the 10 per cent bentonite mixture but wide divergence on the



4 per cent mixture. Hot strength tests were conducted at 2000° F., and 12 min. exposure time on dry sand specimens.

10. However, careful study of the results indicated that the results obtained were not as satisfactory as desirable for research of this type, so a close check of equipment and testing techniques between the two laboratories was made.

#### EQUIPMENT

11. The only differences in equipment found were (1) the hydraulic pressure system on the dilatometer at the Naval Research Laboratory is motor driven while that at Cornell University is manually operated, (2) the Naval Research Laboratory drying oven is of the circulating air type while that at the University is not, (3) the muller-type mixer at the University is of larger capacity (24-in. diameter) than that at the Naval Research Laboratory (18-in. diameter). Both mixers are of the same make, with stationary pan and revolving mullers.

#### MATERIALS AND TEST PROCEDURES

12. Following a conference between the staffs of the two laboratories, it was decided that the following materials and test procedures would be used, in the beginning, for cooperative tests by both laboratories.

##### *Materials*

13. Materials to be used were as follows:

- (1) Base Sand—Standard A.F.A. with 95 per cent of the grains passing the No. 50 and remaining on the No. 70 mesh sieve.
- (2) Western bentonite.
- (3) Distilled water.

##### *Test Procedures*

14. The following procedures were outlined for the two laboratories to follow.

15. *Procurement and Storage of Materials.* A.F.A. Standard sands shall be obtained. Bentonite shall be taken from the stock now on hand at the Naval Research Laboratory. A 100-lb. bag of bentonite shall be split in a sample splitter. The samples shall be placed in 50-lb. capacity lard cans, one being retained at the Naval Research Laboratory and the other sent to Cornell University. A glass dish of calcium chloride shall be placed inside the lard can to dry the clay. When the calcium chloride shows signs of moisture, it shall be replaced with a fresh supply.

16. A similar glass dish shall be kept in the containers holding all base sand samples. This maintains a very low water content in all ingredients and the mixing of batches to accurate water contents will be facilitated.

17. Distilled water shall be used and shall be stored in pyrex bottles which have been thoroughly cleaned with chromic acid and rinsed with distilled water. The bottle top shall be covered with a pyrex beaker and no other stopper used.

18. *Preparation of Sand Mixtures.* The minimum total weight of sand and bonds used shall be 7000 grams per batch and larger when possible. Sufficient water shall be added in excess of this weight to give the desired water content. The dry materials shall be placed in the mixer and mixed dry for 2 min. The calculated amount of water shall be added to the dry mixture and the batch shall be mixed for an additional 5 min. Each mixer shall be kept covered during the entire mixing.

19. *Collection and Storage of Sand Mixtures.* In collecting the sand for storage, only the sand discharged by the operation of the mixer shall be used. The sand remaining in the mixer shall be discarded. The sand shall be discharged onto a 4-mesh screen, equipped beneath with a funnel so that the sand may be riddled directly into a 2-quart jar. The jar containing the sand shall be sealed as soon as it is filled. A test for moisture shall be made at this point (to eliminate a 24-hour delay should the moisture content vary too much from the predetermined value) as well as after the sand has tempered in the jars. The sand mixture shall be allowed to temper in the sealed containers for 24 hours.

20. After tempering, the sand shall be riddled again and tested for room temperature and high-temperature properties.

21. *Room-Temperature Tests.* The following methods shall be used for the room-temperature testing of sand mixtures:

*Moisture.* A "moisture teller" with one-in. high drying pans shall be used. After weighing in the usual manner, the sample shall be dried for 6 min.; cooled to room temperature in a desiccator and reweighed. The water content shall be within 0.115 per cent of that desired. If it is not, the sample shall be discarded and a new mixture made.

*Sample Weight.* A weighed amount of sand shall be placed in the specimen tube, the weight of the sand recorded, and the sand rammed three times.

*Green Permeability.* The Naval Research Laboratory shall use permeability apparatus with orifices. The apparatus shall be calibrated frequently. Cornell University shall use the standard A.F.A. apparatus and procedure.

*Mold Hardness.* After the permeability readings have been made, and before the specimen is stripped, the mold hardness value shall be taken on the exposed specimen surface. Readings also shall be taken on the 1/8-in. diameter specimens used in the high-temperature tests.

*Green Compressive Strength and Deformation.* The green compressive strength shall be measured on a motor-driven sand strength machine. The deformation reading shall be made at this time. Cornell University does not possess this attachment.

*Dry Compressive Strength.* The samples for dry compressive strength tests shall be oven dried at temperatures from 220 to 229° F. for 2 hours and stored in a desiccator. All dry compressive tests, in so far as possible, shall be made with the sand strength machine used in the green compressive strength test and equipped with a special attachment for dry compressive strength testing. If the strength is too high, use shall be made of other available apparatus.

22. *High-Temperature Properties.* High temperature tests shall be conducted as follows:

*Preparation of Specimens.* Samples for both elevated and room temperature testing shall be made at the same time. As before, the weight of sand required to produce a specimen of recommended dimensions shall be recorded. The weighed amount of sand shall be transferred to the specimen tube and be given three rams with the 1½-in. diameter rammer.

*Expansion Tests.* For expansion tests, the dried specimen shall be placed under a 4-oz. load and tested at 800, 1600, and 2500° F., taking the readings at 30-sec. intervals for a 10-min. period.

*Hot Compressive Strength Tests.* Hot strength tests (compression at elevated temperature) shall be tested at 1200, 1600, and 2000° F., after exposure times of 4, 6, and 8 min. The load shall be applied to the specimens within 30 sec. of the end of the predetermined exposure time. Furnace recovery time shall be 3 min., and shall be included in the exposure period.

23. *Standard Mixture to Be Tested.* The tests described above shall be made both by Cornell University and the Naval Research Laboratory on a mixture consisting of

	Per Cent
A.F.A. Standard Sand	95
Western Bentonite	5
Distilled Water	4

24. Tests results then shall be exchanged and shall serve as a basis for further discussion, if there is any abnormal disagreement.

#### RESEARCH PROGRAM

25. After the test procedure was established so that it was possible for each laboratory to duplicate the results of the other, a program of high temperature research was to be inaugurated. This was to cover studies on western and southern bentonite, illite and kaolinite clays, as well as other variables. Each laboratory was to study two of these clays, varying clay content, water content and amount of ramming. Each mixture was to be tested using the procedures previously described. These tests were to be discussed in greater detail after the work of standardizing equipment and procedures was well under way.

### *Reporting Results*

26. On October 20, 1943, Subcommittee 6b7 adopted a method of reporting results for the hot compressive strength tests. The method involves the use of figures and letters; namely, the first figure is the hot compressive strength, the second figure the temperature control setting, the third figure the time the specimen is exposed to heat, and the fourth, the letter D or G referring to whether the specimen was oven dried or green. For example, 400 — 2000 — 6-D, means a hot compressive strength of 400 psi. at a temperature control setting of 2000° F. when the dried sample is exposed to heat for 6 min.

### FIRST TESTS ON STANDARD MIXTURE

27. Following the standardization of procedure, both laboratories, on the same days, made and tested samples of the standard mixture.

### *Results*

28. *Room Temperature Tests.* Except for a difference in the dry compression strength test results, the room temperature tests were satisfactory.

29. *Expansion Tests.* Results obtained in the expansion test again agreed satisfactorily. Because the laboratories had been able to check satisfactorily in expansion test results in two separate sets of check tests, and because interest within the industry had been focused on the hot compressive strength test, Subcommittee 6b7, which directs this work, decided to concentrate on improving the test of greatest interest at that time, namely, the hot compressive strength test. Therefore, in following cooperative work, expansion-contraction tests were not included.

30. *Hot Compressive Strength Tests.* Hot strength tests were made at 1200, 1600, and 2000° F., at exposure times of 4, 6 and 8 min. on oven dried specimens at the same two laboratories on agreed upon days. Comparison of results showed that test data at both laboratories indicated, at each temperature, an increase in hot strength with increases in exposure time. However, differences between data at the same temperature and exposure times at the different laboratories, while in good agreement in some instances, differed rather widely in others and it was agreed that better consistency in results was necessary for this type work.

### *Investigates Equipment and Technique*

31. Following the first tests on the standard mixture, it was decided to investigate the equipment and techniques used at each laboratory more closely than had been done previously.

32. The following were investigated before the second series of check tests on the standard mixture were made:

- (1) *Rammer.* Rammers were compared and adjustments made so that each part was a duplicate of the other in both laboratories.
- (2) *Rammer.* Rammer mountings were compared and both adjusted to an equal degree of rigidity.

(3) *Bentonite.* A check made on the handling of materials before mixing revealed that the bentonite used at Cornell University was oven dried while that at the Naval Research Laboratory was used "as delivered." It was considered that a difference of approximately 4 per cent of mechanically-held moisture in the bentonite would not account for more than a fraction of the difference shown in the hot compressive strength tests.

(4) *Furnace Heating.* While operating the furnace at a temperature control setting of 2500° F. at Cornell, the heating element was red hot on one side and black on the other. This occurred only at the upper end of the heating element. Prof. L. A. Burckmyer, Jr., Dept. of Electrical Engineering, Cornell University, kindly offered his assistance to determine the cause. Tests showed that one third of the impressed voltage was used in a distance 2-in. down from the silicon carbide-carbon block connection (pressure type). This adversely affected the silicon carbide-carbon block connection by increasing its temperature. The aluminum, which had been sprayed on the element end, evidently melted, for globules were formed which produced point contacts with the carbon block.

To avoid the use of a pressure type connection to the element, Prof. Burckmyer suggested a solid metal-to-silicon carbide connection. A satisfactory method of producing this solid connection was obtained. A brass ring was connected to the element by means of copper metal spray. A noticeable drop in electric power consumption was evident immediately. This connection obscured the uneven heating of the element until control temperature settings of 2750° F. were used.

(5) *Electrode Cooling System.* The electrode cooling system was next investigated. Passing of cooling water from the lower to the upper brass electrodes required a large water consumption, if both ends of the element were to be maintained at the same temperature. By cooling each end of the electrode separately and installing thermometers in the outlet water streams, the desired similar temperature was produced at the element ends.

(6) *Air-flow in Heating Unit.* The volume of air passing through the element was found to be considerable, as indicated by the cloud of carbon coming from the upper end when a specimen having an organic binder is placed in the furnace. It is doubtful if the specimen itself is directly affected by this air flow. However, the air probably cools the controlling couple which, in turn, caused a higher element temperature to maintain the control setting. This higher element temperature would be reflected in high temperatures at the ends of the refractory posts.

A metal ring fastened to the bottom triangular plate, having an opening machined to just slip over the lower post holder, was installed



as a seal to prevent the "chimney effect" through the element. At the Naval Research Laboratory, the same results were obtained by wrapping asbestos cloth around the lower post holder.

(7) *Hydraulic Pressure System.* At Cornell, air entering the hydraulic pressure system presented a problem. A new vented piston and lead gasket, used as a seat, were obtained and installed. This, with some additional work, eliminated air leakage into the system at room temperature. However, when the furnace was in operation with the 1½-in. diameter "carbofrax" posts installed, it was not possible to hold 100 psi. for 10 min. as is possible when the furnace is cold. The high heat transfer to the base of the equipment was undoubtedly the cause, for when 1⅛-in. diameter "mullfrax-S" posts were installed, little or no increase in the base temperature took place and it was possible to hold the pressure.

The check valve and a spring loaded valve attached near the small gage have been eliminated from the hydraulic system in the dilatometer at Cornell. The large gage now is connected through a pipe line entirely outside the base of the instrument. All connections are now outside and visible and any oil leaks can be detected quickly.

(8) *Equalization of Heating Element Temperature.* Furnace temperature traverses were employed to check furnace operations as the above changes were made. The point of origin for traverses at Cornell University is the upper triangular horizontal plate. All distances mentioned are downward from that location. Customarily, the traverse thermocouple is lowered into the element chamber (no specimen in furnace) at definite intervals, usually one inch. The indicated temperature readings for each interval are recorded.

When the hot junction of a thermocouple is placed between two surfaces which are at different temperatures, *the thermocouple will indicate some compromise temperature.*

Curves resulting from plotting the indicated temperature against distances downward along the heating element show the following:

- (1) the indicated temperature changes during measurement from top to bottom of the element,
- (2) the curves exhibit variable, limited zones of uniform indicated temperature,
- (3) the position of the uniform indicated temperature zone varies with respect to the opening between the posts,
- (4) the indicated temperatures will vary with (a) presence, or absence, of posts, (b) presence or absence of specimen, (c) with the dimensions of the posts and (d) with the materials of the posts.

(5) The writer found that, if the measuring intervals at the specimen location were shortened to ¼-in., the direction of the

curve at the nose would change direction abruptly two or three times.

33. The fact that the thermocouple indicates a compromise temperature should be considered when evaluating a temperature traverse and when interpreting test results. Considerable time was spent in an endeavor to secure a sample location where the traverse indicated a zone of uniform temperature. Under present conditions, the sample is located with its center  $8\frac{3}{4}$  in. downward from the origin.

#### SECOND SERIES OF TESTS

34. It was not until October, 1943, that the two laboratories were ready to make another set of cooperative tests.

35. To eliminate any differences in mixing or the handling of materials, the mixture used in those tests was made at the Naval Research Laboratory, one half being shipped to Cornell University and the other half retained. Tests were conducted on the same day at each laboratory.

36. Tests for hot compressive strength were conducted at the same temperatures and exposure times as in the first series of tests, namely, 1200, 1600 and 2000° F. and 4, 6 and 8 min. respectively. Results of the tests are shown in Fig. 1.

37. Figure 1 shows good agreement between the laboratories at 1200° F. at all exposure times, but widely divergent results at 1600 and 2000° F., although trends at those temperatures are in the same general direction.

38. It is of interest to note that maximum hot strength was obtained at the Naval Research Laboratory somewhere between 1600° F. at 8-min. exposure and 2000° F. at 4-min. exposure while the maximum appears to occur in the Cornell data at 2000° F. and 6-min. exposure. This would appear to indicate that in the Naval Research Laboratory testing, the plastic zone was reached more quickly than in the Cornell tests. This, in turn, points to a difference in the heating of test specimens between the two laboratories, even though the indicated temperature was the same, or to a difference in testing technique.

39. To further improve the coordination of results between the laboratories, further study of the points investigated after the first series of tests was carried out. In addition, method of impressing voltage in each laboratory was discussed, the platinum-platinum-rhodium thermocouples were heat treated and standardized and the use of the temperature traverse in locating specimens was studied further. The original carbon-block connection to the heating element was restored as the test results obtained with the brass ring, which is a better type of connection, did not warrant the difficulty of affixing the ring.

40. As a result of the further investigation of the temperature traverse to determine the proper position of the sand specimen in the heating unit, Subcommittee 6b7 directed that this method should be used to assure proper specimen position.

## THIRD TEST SERIES

41. The third series of cooperative tests was made in December, 1943. In this series of tests, three different mixtures, as shown in Table 1, were used. The mixtures were prepared at Cornell University and half of each batch shipped to the Naval Research Laboratory. As previously, tests were conducted at each laboratory on the same day. Results of the tests are shown in Fig. 2.

*Discussion of Results*

42. As in the second series of tests, good results were obtained at 1200° F. at all exposures. Comparison of Figs. 1 and 2, show better results at 1600° F. at all exposures than obtained in the second series and less difference at 2000° F. at all exposures.

43. The results obtained at all temperatures and exposure times on mixture 3, Table 1, containing fire clay as a bond, were satisfactory. This would seem to indicate that more difficulty would be encountered in securing check results between laboratories on sand mixtures containing bentonite than on those containing fire clay.

*Rate of Loading*

44. There were some who questioned whether the two laboratories were using the same rate of loading. In the last two test series, the specimens were loaded and ruptured by each laboratory within 10 sec. Therefore, it seems very probable that the two laboratories had very nearly the same sample loading rates. Furthermore, consider mixture 3 of the third series. If the rate of loading was different, and so reflected in the actual variation of the bentonite bonded mixtures, why did the fire clay bonded mixture tests agree so well? On the other hand, if the rate of loading was the same, as it is believed to be, and the fire clay mixtures checked, then it seems apparent that something else, in addition to the rate of loading, is causing the disagreement in the bentonite mixtures.

45. Figure 3 shows the plotted average figures for the same sand mixture for the three test series. What has been said about each individual standard-

Table 1  
SAND MIXTURES USED IN THIRD TEST SERIES

Sand	1	2	3
Kind	St'd. A.F.A.	St'd. A.F.A.	St'd. A.F.A.
Per Cent in Mixture	95	95	90
Binder			
Kind	Western Bentonite	Western Bentonite	Fireclay
Per Cent in Mixture	5	5	10
Per Cent Moisture (212° F.)	2.8	6.8	2.6
Distilled Water			
Per Cent in Mixture	3.9	3.85	3.8

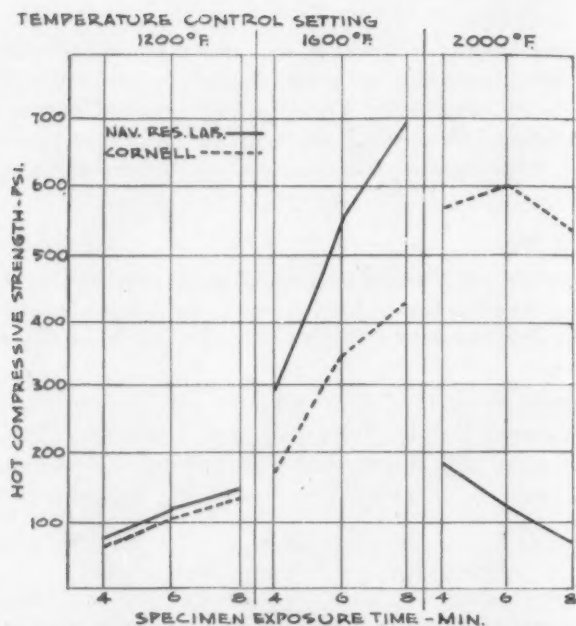


FIG. 1—RESULTS OF SECOND SERIES OF TESTS ON STANDARD MIXTURE (OCTOBER, 1943).

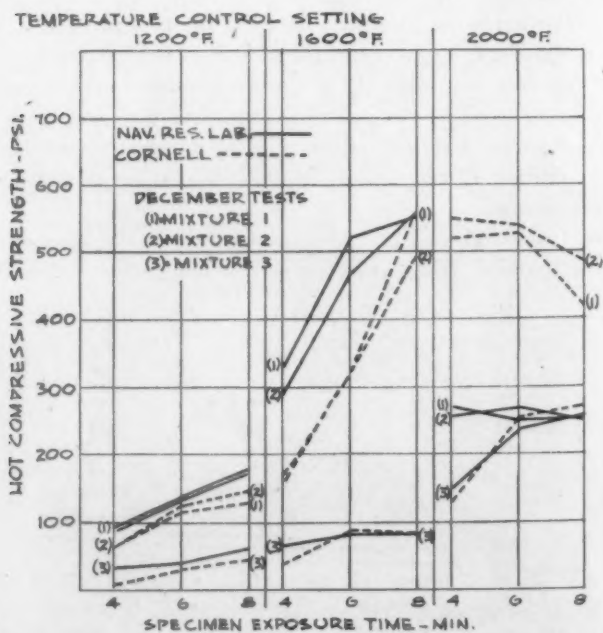


FIG. 2—RESULTS OF THIRD SERIES OF TESTS ON MIXTURES SHOWN IN TABLE 1 (DECEMBER, 1943).

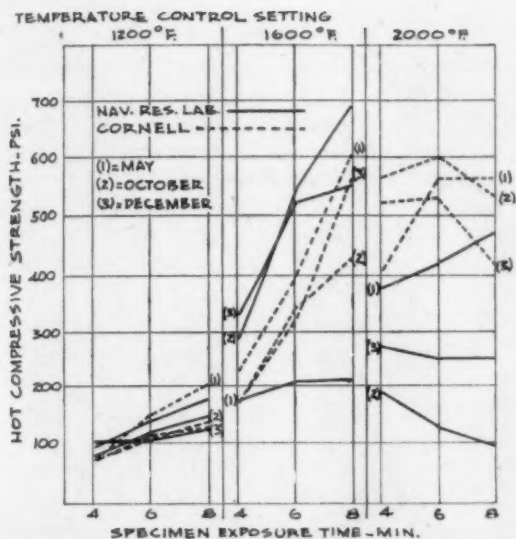


FIG. 3—AVERAGE RESULTS OF THREE TEST SERIES ON STANDARD MIXTURE.

ization test applies to these curves and figures; namely, (1) at 1200° F., the tests agree, (2) at 1600° F., the curves move in the same direction but actual test values, while not too satisfactory, show improvement as testing progressed, and (3) at 2000° F., the results are not satisfactory, but also show improvement as testing progressed.

#### FOURTH TEST SERIES

46. In February, 1944, the check test program was expanded to include the laboratories of the H. W. Dietert Co., Detroit, and the Experiment Station, Hercules Powder Co., Wilmington, Del., and the following procedure arranged for the four laboratories:

(a) Each laboratory was to mix and send to the other three laboratories: (1) sufficient green sand, in a tightly sealed container, to make room temperature tests and hot compressive strength tests on green sand specimens and (2) a sufficient number of dried (at 212°-220° F.) specimens to make the required number of hot compressive strength tests.

(b) Each laboratory was to have the specimen location in their respective furnaces in the zone of uniform temperature, as indicated by a temperature traverse.

47. The averages for each laboratory for each condition of temperature control setting and exposure time is shown in Table 2. Table 3 shows the difference in psi. for each testing condition for each laboratory from the highest to the lowest value obtained.

48. The agreement between the laboratories is not too good. One possible



**Table 2**  
RESULTS OF FOURTH CHECK TEST SERIES

	<i>Naval Research Laboratory</i>	<i>H. W. Dietert Company</i>	<i>Hercules Powder Company</i>	<i>Cornell University</i>
<i>Green Properties</i>				
Specimen Weight, grams	155	156	156.2	155
Green Permeability	83	78.2	88	75
Green Compression, psi.	5.9	6.1	6.1	6.3
Mold Hardness	71-76	71-75	77-74	79-79
<i>Average Hot Compressive Strength, psi.</i>				
1200-6-G	221	219	265	..
1600-6-G	575	716	637	389
2000-6-G	125	90	98	371
1200-12-G	315	363	344	209
1600-12-G	670	721	669	570
2000-12-G	230	159	143	489
1200-6-D	126	115	136	83
1600-6-D	323	266	293	114
2000-6-D	78	44	70	184
1200-12-D	166	130	136	116
1600-12-D	353	308	322	159
2000-12-D	131	55	101	298

reason for the variations might be that each laboratory used a different rate of loading.

49. Only one set of determinations was made. The program is to be continued only after each dilatometer is equipped with the new yoke and upper post assembly.

#### VARIABLES STUDIED

50. Following are some variables which may be encountered between two laboratories endeavoring to duplicate the other's work:

##### *Location of Controlling Thermocouple Bead*

51. This point was settled before the first test series on the standard mixture was made. The location of the hot junction of the controlling thermocouple was arbitrarily placed in the heating chamber and opposite the center of the specimen. No work has been done with the thermocouple bead in any other location.

##### *Rate of Table Rise*

52. All testing was done on an alleged basis of uniform table rise (constant strain rate). Theoretically, the dilatometer at Cornell University can be operated at any *chosen* rate because it has a hand-operated pressure system. At the Naval Research Laboratory, the pressure system is motor operated at a

Table 3

RANGE IN PSI. BETWEEN HIGH AND LOW VALUES FOR EACH PARTICIPATING LABORATORY AT THE DIFFERENT TESTING CONDITIONS

	<i>Naval Research Laboratory</i>	<i>H. W. Dietert Company</i>	<i>Hercules Powder Company</i>	<i>Cornell University</i>
1200-6-G	35	53	100	..
1600-6-G	203	110	142	311
2000-6-G	19	27	15	62
1200-12-G	25	3	127	25
1600-12-G	214	17	315	171
2000-12-G	20	16	48	419
1200-6-D	29	26	48	32
1600-6-D	63	35	43	39
2000-6-D	8	17	10	89
1200-12-D	28	43	45	45
1600-12-D	64	37	108	78
2000-12-D	25	7	15	55

fixed rate. This fixed rate is equivalent to a table rise of 1-in. per min. and can be obtained on the manually operated system by turning the screw at 30 rpm. The above rate is for a table rise when *there is no specimen being tested*.

53. When the hydraulic system is air free, the table rise at a rate of 1-in. per min. will prevail whether or not a test specimen is in the furnace. In this case, the figures on deformation, shown in Table 4, would apply.

To the writer's knowledge, no such deformation figures, as shown in Table 4, corresponding to specimen breaking times of 10 sec. or more ever have been reported.

54. Any air in the hydraulic system greatly alters the rate of table rise. For example, at Cornell University, the following figures were obtained for a rate of manually turning the crank at 30 rpm.

Table 4

DEFORMATION OF SPECIMEN WHEN RATE OF TABLE RISE  
IS ONE INCH PER MIN.

<i>Time to Break Specimen, sec.</i>	<i>Distance of Table Rise, in.</i>	<i>Deformation, in. per in. (<math>1\frac{1}{2} \times</math> 2-in. Specimen)</i>
1	0.0166	0.0083
5	0.0830	0.0415
10	0.166	0.083
15	0.249	0.1245
20	0.332	0.166
30	0.498	0.249
60	1.000	0.500

- (1) No load condition—table rise 1 in. per min.
- (2) Time required to reach 500 psi. with undetermined amount of air in hydraulic system—90 sec.
- (3) After removing as much air as possible from the hydraulic system, the time required to reach 500 psi.—30 sec.

55. Thus two different rates of table rise at 30 rpm. were obtained and neither approached the rate desired. Therefore, it seems doubtful if the recommended table rise (1 in. per min. under no load condition, equivalent to 30 rpm. of the manually operated hand crank) is an accurate designation to describe the rate of table rise. (See Appendix for contributions from other individuals, including Subcommittee members, regarding this subject.)

*Straining of the 1½ x 2-in. Specimen When Stripping from Tube*

56. This problem has not been investigated as yet. A split sample tube has been made at Cornell University and may eliminate some irregularities caused by the stripping action. This investigation should conceivably be carried on simultaneously with the development, shape, size and ramming of the sample.

*Dissimilarity of Heating Elements*

57. During the writer's investigation of the heating uniformity of the furnace element, it was found that (1) the wall thickness of a heating element was not the same all the way around, and that (2) no two heating elements used measured alike. This variation in the element wall might have an effect on the evenness with which the sample is heated. From observations on three elements used, the red-hot spots, at the top of the element, were found on the thinnest wall sections. The inside contour of the element varied and probably caused further differences in the heating of the specimen.

58. After the writer's visit to the company manufacturing the heating elements, improvement in fabrication of the element seemed doubtful because:

- (1) The element is made from aggregate material, the particle size of which is difficult to control,
- (2) the element is rammed in a mold,
- (3) firing of the element is carried out in a chamber where it cannot be observed, and
- (4) demand for this type of heating element is very limited.

*Refractory Posts and Disks*

59. The dimensions, as well as the material of which the posts and disks are made, offer a field for much investigation. Up to the time this investigation was begun, posts and disks of a material known as "carbofrax" had been used. The writer made limited tests using posts made of a material known as "mull-frax-S" which were satisfactory under the conditions in which they were used and tested. Before selecting the proper material, it was deemed advisable to make a thorough survey of temperature conditions within the furnace under all conditions of testing.

### *Effect of Replaced Parts on Sample Location*

60. Due to variations between elements and possibly posts, it may be necessary, after replacements of such parts are made, to alter the sample location because the temperature distribution within the heating unit may be changed.

### *Continuous Operation vs. Overnight Furnace Shut Down*

61. When the writer first began to operate the dilatometer, it was the practice to heat up the furnace each morning and shut it off each night. This was found to be poor practice as it

- (1) shortened the life of the element, and
- (2) of the more importance, the fact that, near 400° F., a considerable volume change occurs, due to the presence of cristobalite ( $\text{SiO}_2$ ).

62. Cristobalite is formed by the reaction of silicon-carbide and oxygen at higher furnace temperatures. The heating and cooling of the element through the above-mentioned temperature region for cristobalite causes micro-cracking on the element. Hot spots probably result so that temperature conditions may vary within the chamber from day to day. The makers of the elements recommend continuous operation and for overnight heating, an idling temperature of not less than 1150-1200° F.

### *Time Required for Furnace to Come to Constant Conditions*

63. The usual procedure in dilatometer operation is to heat up the furnace each morning. After the control temperature is reached, one half hour is allowed to establish constant conditions. This point has been investigated and it seems doubtful if constant conditions are reached within 4 or 5 hours. For the past 6 months, the practice at Cornell University has been

- (1) to keep the furnace heated continuously,
- (2) to operate at only one temperature control setting in any given day, and
- (3) at night, to set the control for the next day's operating temperature.

Two laboratories differing in this procedure might have difficulty duplicating work.

### *Oiling Rammer Rod*

64. The usual practice is to oil the rammer rod. At Cornell University, this practice was not found advisable. The oil oxidizes and creates friction along the rod where the sliding weight drops. This oxidized oil was removed and an increase in weight of 2 grams was obtained for the 2 x 2-in. specimen and 0.8 grams for the 1 1/8 x 2-in. specimen.

### PILOT INVESTIGATIONS

65. The term "pilot" has been given to the following investigations because, (1) generally only one limited set of determinations was made, and (2) it was

desirable to learn whether or not the subjects investigated warranted a more detailed study.

#### *Refractory Posts of 1 1/8-in Diameter*

66. Earlier in this report, when discussing the hydraulic pressure system, the writer referred to the high heat transfer to the pressure loading mechanism. "Carbofrax" is an excellent refractory for heat transfer. To reduce the heat transfer, a lower post was made of a material known as "alfrax-K." Dimensions of the post were 1 1/8-in. diameter on one end and tapered to 3/4-in. diameter on the other. Several of these posts were tried but were found too weak to be of use. The refractory manufacturer was consulted and recommended another material known as "mullfrax-S" for a post 1 1/8-in. diameter throughout its length. Three upper and lower posts made of that material were obtained.

67. Immediately after the completion of the December (third series) tests, the new 1 1/8-in. diameter posts were installed. A sufficient number of additional samples had been made from the same mixture as used in the third test series and these were used to test the effect of the new type posts with the results shown in Fig. 4.

#### *Discussion of Results*

68. Figure 4 shows the averages obtained from the third series of tests using the "carbofrax" posts and the averages using the 1 1/8-in. diameter "mullfrax-S" posts. The regular disks were used at the top and bottom of the specimen. At a temperature control setting of 1200° F., mixtures 1 and 2 tested on the "mullfrax-S" posts did not show curves similar to those when using the "carbofrax" posts. At a temperature control setting of 1600° F., tests using the different posts showed little change for mixture 2, while the strength at 8 min. exposure time for mixture 1, was much lower using the "mullfrax-S" posts. At a temperature control setting of 2000° F., tests using "mullfrax-S" posts showed an appreciable increase in strength. Tests on mixture 3 showed lower strengths with the "mullfrax-S" posts.

69. *Advantages of 1 1/8-in. Diameter "Mullfrax-S" Posts.* It is much easier to center the 1 1/8-in. diameter posts in the furnace. As the posts are the same size as the specimen, no trouble is encountered in centering the specimen on the lower post. These solid "mullfrax-S" posts were subjected to a maximum pressure of 673 psi. The limiting pressure that these posts will stand is not known. The "mullfrax-S" material is easily ground and shaped, making it possible to have very smooth ends. It is probable that these "mullfrax-S" posts are a satisfactory material, but after observing Fig. 4, users would not expect to obtain the same results as when using "carbofrax" posts.

#### *"Alfrax-K" Disks*

70. The present type of disk material is "carbofrax," a high heat transfer material. "Alfrax-K" has a heat transfer value one-fifth of "carbofrax." Disks



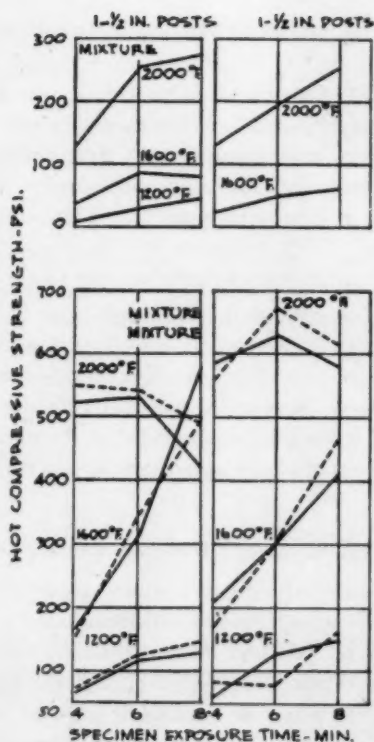


FIG. 4—RESULTS OF TESTS ON MIXTURES USED IN THIRD TEST SERIES USING (LEFT) CARBOFRAX AND (RIGHT) MULFRAX-X POSTS. MULFRAX-X POSTS WERE  $1\frac{1}{8}$ -IN. DIAMETER AS AGAINST  $1\frac{1}{2}$ -IN. DIAMETER FOR THE CARBOFRAX POSTS.

of "alfrax-K" were obtained and used. The top disk broke with each hot compressive strength test. However, the results obtained were lower than those obtained when using the regular disks. Thus, the hot compressive strength may be profoundly changed by changing material used in the disks. A continued study of disks and materials of construction should be made.

#### *Breaking of Platinum vs. Platinum-10 Per Cent Rhodium Thermocouple*

71. In the present furnace chamber, the controlling thermocouple bead is placed opposite the center of the specimen. Every so often, the thermocouple wires part just below the protecting shield.

72. When the specimen breaks, sand grains fly. On January 17, a new bead was made on the controlling thermocouple. On February 4 (19 days later), the control system began to give trouble. The couple was removed for inspection. The bead was observed under the microscope and sand grains were found fused to the bead and wires below the protecting shield. The wires appeared almost *notched* through. The metallic surface, when it could be seen, appeared crystallized in some definite pattern. Contamination, and its

resulting change in the electromotive force-temperature relationship, was considered.

73. From Langes *Handbook of Chemistry*\*, it was learned that platinum can be contaminated by  $\text{SiO}_2$ . When the thermocouple was checked against a chromel-alumel couple, it was found that they agreed. Under conditions which the thermocouple is used, the bead and wires may be contaminated but the temperature -e.m.f. relationship gives true Platinum vs. platinum 10 per cent Rhodium readings. The thermocouple was used only two more days before the flying sand grains severed the wires and a new bead had to be made.

74. At the same time as the thermocouple was being examined, it was noticed that the element, all around the specimen location, was covered with sand grains. These grains came from the specimens as they broke. The grains were removed easily when the element was cold. Because of the area covered by these sand grains, it is doubtful if the bead of the controlling thermocouple located level with the bottom of the upper post would be free from the abrasive flying grains.

#### *Temperature of Posts and Element (Methods A and B)*

75. Towards the latter part of 1943, a new technique for making the hot compressive strength test was proposed and designated as "Method B" by the maker of the dilatometer. "Method A" was the designation given to the technique previously used. When using "Method B," the furnace is preheated to some temperature so that, when the furnace is lowered over the specimen, the controlling couple will indicate "desired test temperature."

76. As previously stated, the controlling thermocouple registers only a compromise temperature instead of the "desired test temperature." Since the burden of proof rested with the writer, chromel-alumel thermocouples were secured to the upper and lower posts and the element to ascertain the temperature of each at a specified control setting. On the posts, the thermocouples were fastened to the faces presented to the disks. The thermocouple attached to the element was located as near as possible to the bead of the controlling couple. Sauereisen cement was used to fasten the thermocouples in place. By means of a suitable switching arrangement, all temperature readings were made on one potentiometer.

77. *Test Procedure.* Specimens were installed on the posts as specified by methods A or B. The average time to insert the specimen and close the furnace was 8 sec. Due to the large difference in temperature of the parts being measured at 15 sec. intervals, it was impossible for the temperatures of the two posts and element to be taken during any single exposure time. The data given for the upper and lower posts and element at any chosen test temperature is taken from separate tests. Samples used were from the same mixture and all made at the same time.

\*p. 1195, First Edition.

78. For "Method B," the temperature to which the furnace was preheated for a test temperature of  $1600^{\circ}\text{F.}$  was  $1825^{\circ}\text{F.}$ , and for a  $2000^{\circ}\text{F.}$  test temperature, the furnace was preheated to  $2250^{\circ}\text{F.}$  The idling temperature of the parts examined was taken after the furnace had idled overnight at the test temperature control-setting. Idling overnight was considered long enough for the furnace to reach its constant temperature condition.

79. *Results.* Figure 5 shows the results obtained for "Method B" at a test temperature of  $1600^{\circ}\text{F.}$  Temperatures are plotted against specimen exposure times. The temperature drop of the upper post was surprising at first. It must be remembered that the lower end of the upper post, when the furnace is being moved, is in close relationship to the cooler part of the element, and when the furnace is in the upper position, the post end is very close to the water cooled electrode. The loss of heat by radiation is much greater here than from the lower post which is in the open. Temperature conditions at the end of 5 min. exposure time were found to be above the "desired test temperature" of  $1600^{\circ}\text{F.}$

80. Figure 6 shows the results for "Method B" at a "desired test tempera-

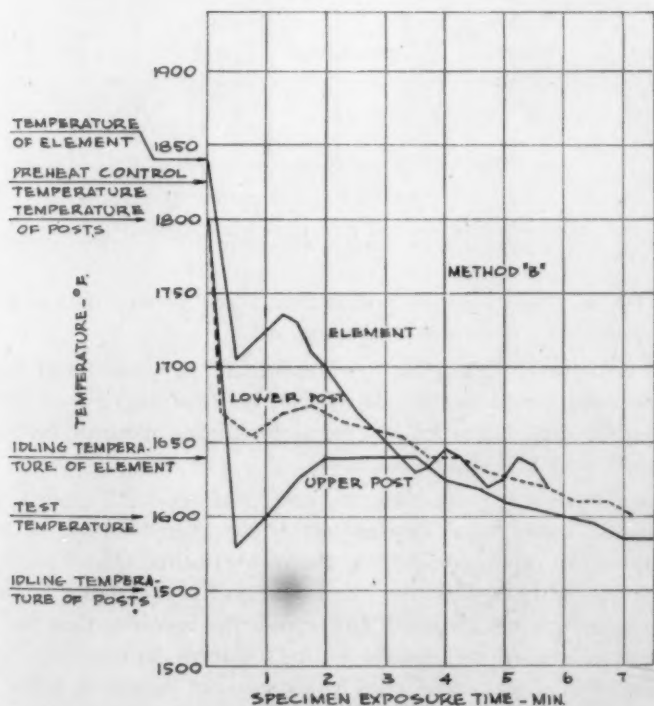


FIG. 5—TEMPERATURES OF HEATING ELEMENT AND POSTS OBTAINED BY HEATING FURNACE TO CONTROL TEMPERATURE OF  $1825^{\circ}\text{F.}$  TO SECURE A TESTING TEMPERATURE OF  $1600^{\circ}\text{F.}$  AT VARIOUS EXPOSURE TIMES (METHOD B).

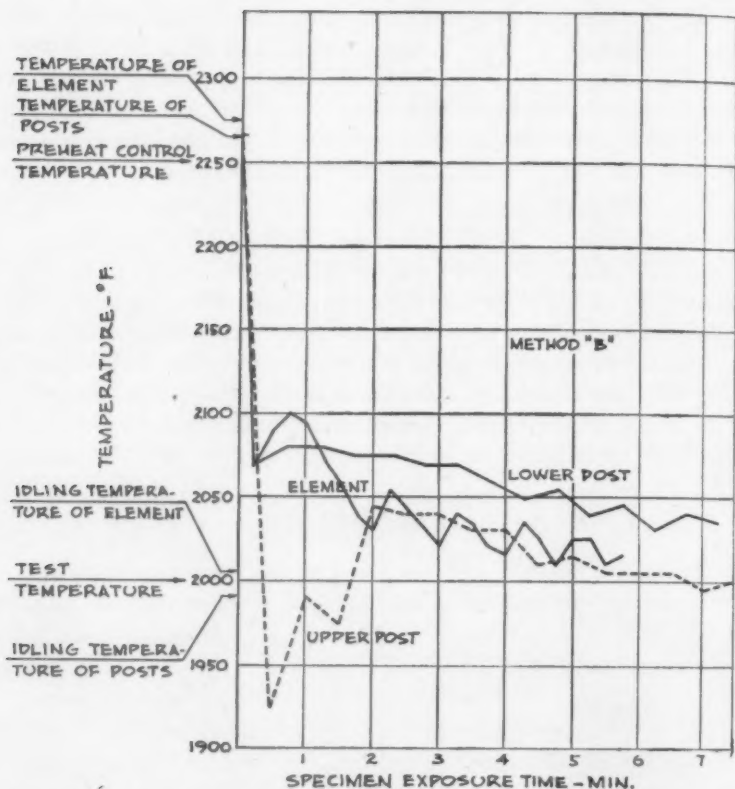


FIG. 6—SAME AS FIG. 5 BUT HEATING FURNACE TO 2250° F. TO SECURE TESTING TEMPERATURE OF 2000° F. (METHOD B).

ture" of 2000° F. After 5 min. exposure time, it will be seen that temperatures were still above the "desired test temperature."

81. All tests were made using specimens made of washed and dried sand having good reflective properties. It will not be surprising if the temperature curves are quite different when specimens containing natural clay substance or other good heat absorbents are used.

82. The temperature measurements using "Method A" (the usual technique) were all made at a "desired test temperature" setting of 2000° F. Figure 7 shows the results obtained as the recovery time was changed for the 2000° F. control setting. Data for the lower post is not shown, as it closely follows the curve for the element. Decreasing the recovery time indicated a greater over heating of the control setting. Curves for recovery times between 2 min. and 55 sec. and 7 min. 55 sec. are not shown on Fig. 7 as they fall between the two shown.

83. When using 36 volts for recovery and reducing to 30 volts at the

end of 2 min. and 15 sec. it was hoped that all parts concerned would be brought closer to the test temperature. Figure 8 shows the results obtained. It is reasonable to expect that this particular voltage and time of voltage change would be applicable only for the mixture tested.

### *Size of Thermocouple Wires*

84. During a visit to the Naval Research Laboratory in September, 1943, the writer noticed the large size of the controlling thermocouple wires and the protecting shield used on the dilatometer in use there. Since the controlling thermocouple wires and protecting shield on the dilatometer at Cornell University were of smaller size, it occurred to the writer that there might be some difference in temperature measurement at the two laboratories, due to this difference in size.

85. Recently, and at temperatures below the boiling point of water, the writer has observed the following experiment performed to determine surface temperature: Two thermocouples of the same material, one of 28 gage wire and the other of 20 gage wire, were embedded to equal depths in an isothermal plane. The lead wires were perpendicular to the plane being meas-

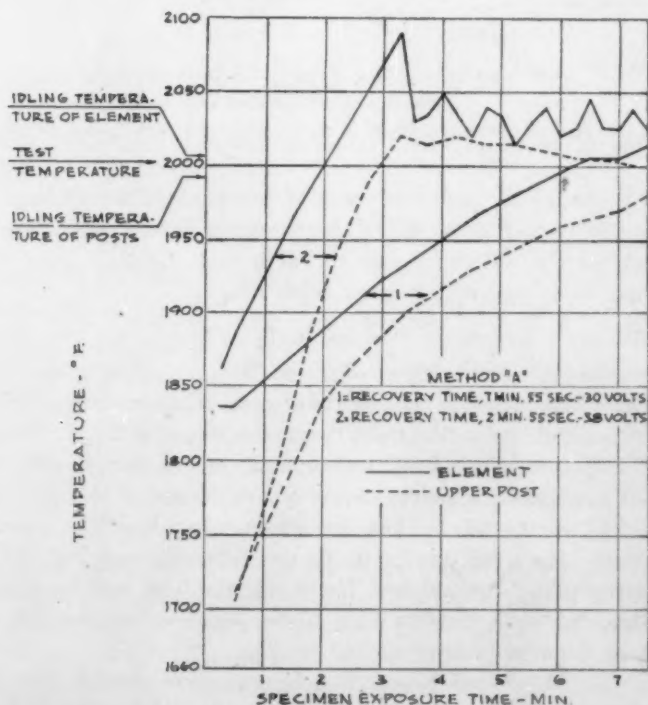


FIG. 7.—HEATING ELEMENT AND UPPER POST TEMPERATURES DEVELOPED WHEN INSTRUMENT IS SET AT 2000° F. AND FOR A TESTING TEMPERATURE OF 2000° F. (METHOD A) AT VARIOUS EXPOSURE TIMES.

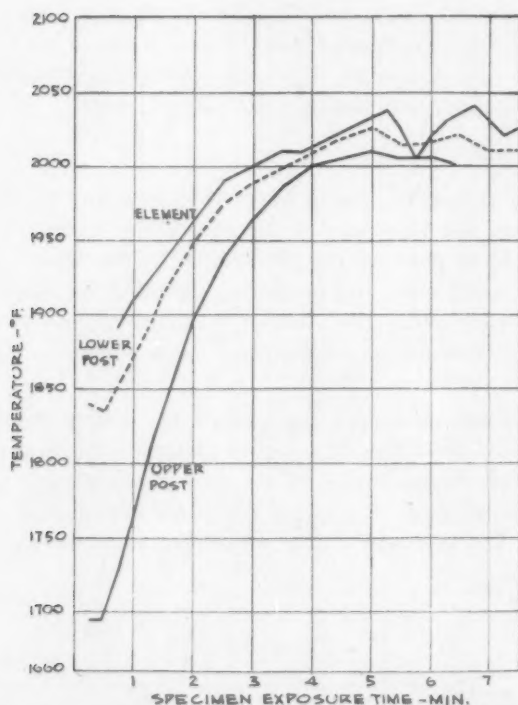


FIG. 8—EFFECT OF REDUCING VOLTAGE FROM 36 TO 30 VOLTS AFTER 2 MIN. 15 SEC. EXPOSURE ON TEMPERATURE OF HEATING ELEMENT AND POSTS AT VARIOUS EXPOSURE TIMES USING PROCEDURE OF METHOD A.

ured and extended out into the room temperature. The 28 gage thermocouple indicated from 25 to 30° F. higher than the 20 gage thermocouple. The reason for the difference was the ability of the lead wires of the 20 gage thermocouple to conduct away more heat.

#### *Points to Consider Regarding Thermocouple*

86. Since the above variation of 25 to 30° F. occurs below the boiling point of water, the question immediately arose, what is probably the difference in temperature indication from thermocouples of different sizes at 2000° F.? This subject has not been investigated in connection with the dilatometer but the following points should be considered:

(1) Heat will be lost by conduction along the thermocouple wires. Heat will be lost from the exposed bead and wires to the surrounding atmosphere. The larger the wire and bead the greater the heat loss, resulting in a higher element temperature to maintain the temperature control setting.

(2) The Naval Research Laboratory consistently finds the peak strength, of the sand mixes tested, to be 200 to 400° F. lower than the peak strength temperatures found at Cornell University. The



difference in controlling thermocouple wire sizes at the two laboratories could easily contribute much to the variation in test results previously reported.

(3) The length of lead wire from the controlling thermocouple bead should not extend past the binding post block on the top of the furnace. Excess wire at the binding posts gives the opportunity for more heat loss to the room atmosphere. Two laboratories making check tests should have their extension leads to the control instrument made of the same materials and of the same lengths.

(4) Since the steering committee of Subcommittee 6b7 has temporarily decided that the temperature traverse shall be used to determine the sample location, and in light of the preceding points, care should be taken to insure that the traverse thermocouple assembly be practically identical to the controlling thermocouple assembly. At each positioning of the traverse thermocouple, time must be allowed for the new rate of heat loss to become constant before the reading is taken.

(5) A large difference between the size of thermocouple wire used and the bore of the protecting shield might increase the heat loss due to the chimney effect through the shield.

(6) The writer has found a two section tube of clear fused quartz to be an excellent protecting shield.

(7) One way to minimize the difference between the temperature control setting and the element temperature required to maintain that setting, would be to use the smallest size wire possible and make a very small thermocouple bead.

#### *Alpha-Quartz in Western Bentonite*

87. As the cooperative program between the Naval Research Laboratory and Cornell University was being formulated, Prof. J. R. Moynihan agreed with the writer that a partial analysis of the bentonite used should be obtained. For the standardization tests, the Naval Research Laboratory split a bag of bentonite. They retained one part and shipped the other part to Cornell University. It so happened that this split bag of bentonite was of the same brand as the bentonite on hand at Cornell University. The writer secured an x-ray analysis of the two lots.

88. The presence and amounts of alpha-quartz and alpha-cristobalite were desired. Mr. Stroupe, Cornell University, made the x-ray analysis and his conclusion follows: "Thus we come to the conclusion that, in the Cornell material, there is about 17 times as much bentonite as alpha-quartz per unit volume, whereas in the Navy material, there is only about eight times as much bentonite as alpha-quartz and consequently the amount of alpha-quartz per unit volume in the Navy material is very roughly twice that in

the Cornell material." No alpha-cristobalite was found in either stock of bentonite.

89. Also a partial chemical analyses of the two stocks of bentonite were obtained. These analyses along with the *average* analysis, as given in the producer's literature, and an analysis of a bentonite from Upton, Wyoming\*, are shown in Table 5.

90. The partial chemical analysis was made by Mr. Fainberg, Cornell University. The two stocks of bentonite differed mainly in the percentages of the alkali oxides present. The green compression tests on the two stocks of bentonite differed 0.9 psi. Some part of this strength difference may be reflected in the alkali contents of the two stocks, due to the difference in sizes of the sodium and potassium atoms, and the amounts of each present. The alpha-quartz in the bentonite may give the effect of imparting green strength to a sand mix as would the addition of the finest silica flour.

91. The question then arose, would the two stocks of bentonite give the same results for the hot compressive strength test? In the cooperative tests made in December (third series) mixture 1 was made with "Navy" stock bentonite and mixture 2 with "Cornell" stock. The averages for the tests are found plotted in Fig. 2. In most cases, mixture 2 was found to give slightly higher hot compressive strength when the sample was broken within 10 sec. after starting the application of load.

92. Another set of tests were made to compare the two stocks of bentonite. This time the bentonites were dried overnight in the oven to eliminate the effect of mechanically held moisture. In the hot strength tests, the compressive loading was done by turning the hand crank at 30 rpm. Table 6 gives the results of the room temperature tests.

93. *Room Temperature Properties.* These checked well with the possible exception of the dry compression strength. The dry compression tests were made using the dilatometer at room temperature. The loading was at the rate of 100 lb. per min. as specified by the A.F.A. standard. The difference in green compressive strength for the two mixtures is approximately one psi.

94. *Hot Compressive Strength Tests.* The averages for the hot compressive strength tests are plotted in Fig. 9. Comparing this set of tests with the previous set (Fig. 3), it will be found that the relative positions of the mixes are reversed. In the later set, mixture 2 is always lower in hot compressive strength whereas, in the previous test, mixture 2 was generally higher. No comparison of actual test values can be made as the rate of table rise was not known for the two tests.

95. The writer believes that further study of the constituents of bentonite would benefit sand control. If the amount of alpha-quartz in bentonite makes a difference, it could never be found by the empirical method of investigation.

\*"Differential Thermal Analyses of Clay Minerals and Other Hydrous Materials," Grim, R. E., and Rowland, R. A., AMERICAN MINERALOGIST, vol. 27, no. 11, p. 756 (1940).

**Table 5**  
**ANALYSES OF VARIOUS BENTONITES**

<i>Substance</i>	<i>Navy Stock</i>	<i>Cornell Stock</i>	<i>Producer</i>	<i>Grim and Rowland</i>
SiO <sub>2</sub> , per cent	64.25	62.25	64.32	64.32
Al <sub>2</sub> O <sub>3</sub> , per cent	21.06	21.57	20.74	20.74
Fe <sub>2</sub> O <sub>3</sub> , per cent	3.31	3.60	3.03	3.03
FeO, per cent			0.46	0.46
MgO, per cent			2.30	2.30
CaO, per cent			0.52	0.52
Na <sub>2</sub> O, per cent	3.24	1.39	2.59	2.59
K <sub>2</sub> O, per cent (less than)	0.1	0.53	0.39	0.39
TiO <sub>2</sub> , per cent			0.14	0.14
H <sub>2</sub> O (chemically held), per cent			5.15	5.15

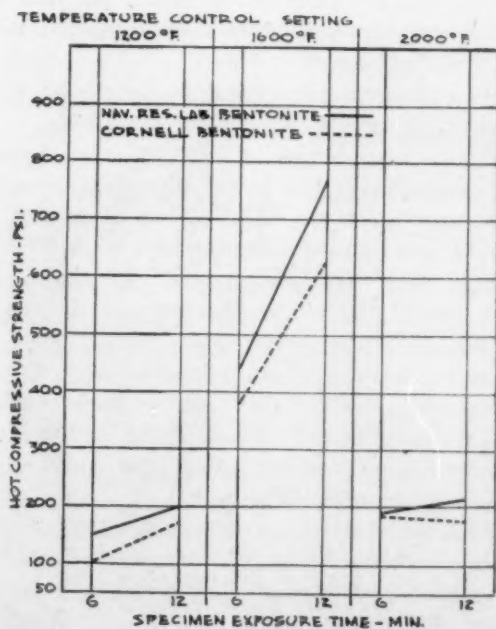


FIG. 9—HOT COMPRESSIVE STRENGTHS OF MIXTURES IN TABLE 4 USING DIFFERENT BENTONITE SAMPLES.

**Table 6**  
**ROOM TEMPERATURE PROPERTIES IN TEST COMPARING BENTONITES**

	<i>Mixture 1</i>	<i>Mixture 2</i>
Moisture, per cent	7.5	7.6
Sample weight, grams	159	158
Green Permeability	165	176
Green Compression Strength, psi.	4.9	5.8
Dry Compression Strength, psi.	100	100

## OBSERVATIONS ON RINDING AND CORING OF SAMPLE

96. Shortly after the writer began work in March, 1943, he tested numerous samples at various temperature control settings to determine the retained compressive strength after a specimen exposure time of 20 min. The condition of the specimens on removal from the dilatometer for observation is noted below:

(1) At a temperature control setting of 1800° F., a circular crack could be seen on the top of the specimen which indicated that, after shock heating, the specimen was composed of two parts, a "rind" and a "core." This rind had a wall thickness of 1/4-in. From a central horizontal crack in the rind, vertical cracks extended to the specimen ends. There were always six evenly spaced radial cracks in the rind on the sample top surface. *In this, and subsequent observations on bentonite bonded mixes, the rind level was visibly above that of the core.* It seems possible that this may be an exhibition of alpha-beta quartz inversion.

(2) At a temperature control setting 1900° F., the same was observed as at 1800° F.

(3) At a control setting of 2000° F., there appeared one large vertical crack running the length of the specimen. On either side of the vertical crack, the rind had two levels with a gradual slope around the specimen between the two levels. The core level was still lower. After standing at room temperature for 8 min., the elevated part of the sample receded and the top was all at the same level.

(4) At a temperature control setting of 2200° F., the circular crack appeared, and the rind wall thickness still measured 1/4-in.

(5) At a temperature control setting of 2400° F., the circular crack appeared on top, but was a little smaller in diameter, and the core diameter was 1/4-in.

(6) At a temperature control setting of 2500° F., the same was observed as at 2400° F.

97. The same kind of rind and core action was observed when the specimen exposure time varied from one to 20 min. Although Preston and White\* were interested in a clay study, they may have given the explanation of the rind and core action found on sand specimens.

98. This formation of rind and core suggests that the specimen should be under observation during testing. It also suggests that, from the hot compressive strength test, only some "nominal" compromise strength of the rinded and cored specimen may be obtained. At some temperature control settings, the strength found may be dependent upon either the rind, the core, or both, and the respective areas presented to the external force applied.

\*JOURNAL, American Ceramic Society, vol. 17, p. 137 (1934).

99. As the rind does not separate from the core in a true vertical plane, and as the contour of the rind-core interface undoubtedly varies from specimen to specimen, this may be one reason for variation between tests. As dried or baked compressive tests at room temperature exhibit nothing visibly analogous to the rind-core action at elevated temperatures, the writer believes that there is an entirely different problem to solve when testing at elevated temperatures.

100. An explanation of rind and core formation may be that all the sand grains in the rind have passed through the alpha-beta quartz inversion and have attained a temperature of at least  $1037^{\circ}$  F., and the grains which compose the core are likely at some temperature below  $1037^{\circ}$  F.

101. One method which usually gives a demonstration of the rind-core action during the hot compressive strength test follows. The test is made as usual, except that, during the compression loading, the furnace is in the upper position. (*Caution:* operator and observers should be protected from flying hot sand grains.)

102. This phenomenon of a rind separating from a core at elevated temperatures in sand specimens, invites numerous questions regarding both the hot compression strength test and the expansion test. The writer expects to investigate the effects of this phenomenon on those tests in the future.

#### NOTE

103. The term "temperature control setting" has been used throughout this report. This term is used because the writer feels that the potentiometer registers only a compromise temperature between the temperatures of the element and the specimen.

#### SELECTED BIBLIOGRAPHY

104. In addition to articles found in the *Transactions of the American Foundrymen's Association*, the following have been selected:

1. Browning, G. M., and Milam, F. M., "Effect of Different Types of Organic Materials and Lime on Soil Aggregation," *SOIL SCIENCE*, vol. 57, p. 91 (1944).
2. Buswell, A. M., and Dudenbastel, B. F., "Spectroscopic Studies of Base Exchange Materials," *JOURNAL, American Chemical Society*, vol. 63, p. 2554 (1941).
3. Chesters, J. H., and Parmelee, C. W., "The Measurement of Reaction Rates at High Temperatures," *JOURNAL, American Ceramic Society*, vol. 17, p. 50 (1934).
4. Clark, R. E. D., "New Effects Due to Anisotropy of Colloidal Particles," *SOCIETY OF CHEMICAL INDUSTRY*, vol. 62, no. 37, p. 348 (1943).
5. Coronet, I., "Sorption of  $N_2$  on Montmorillonitic Clay," *JOURNAL OF CHEMICAL PHYSICS*, vol. 11 (5), p. 217 (1943).
6. Evans, R. H., and Wood, R. H., "The Modulus of Elasticity of Materials for Small Stresses," *PHILOSOPHICAL MAGAZINE*, vol. 21, ser. 7, no. 138, p. 65 (1936).
7. Goodeve, C. F., "A General Theory of Thixotropy and Viscosity," *TRANSACTIONS, Faraday Society*, vol. 351, p. 342 (1939).
8. Grim, R. E., and Rowland, R. A., "Differential Thermal Analyses of Clay Min-



erals and Other Hydrous Materials," AMERICAN MINEROLOGIST, vol. 27, no. 11, p. 746 (1942); no. 12, p. 801 (1942).

9. Haladay, L. L., "Proportion of Energy Radiated by Incandescent Solids in Various Spectral Regions," JOURNAL, Optical Society of America, vol. 17, p. 239 (1928).

10. Hendricks, S. B., "Lattice Structure of Clay Minerals and Some Other Properties," JOURNAL OF GEOLOGY, vol. 50, p. 276 (1942).

11. Hendricks, S. B., Nelson, R. A., and Alexander, L. T., "Hydration Mechanism of Clay," JOURNAL, American Chemical Society, vol. 62, p. 1457 (1940).

12. Hulbert, E. O., "Reflectivity of Sand and Snow," JOURNAL, Optical Society of America, vol. 17, p. 23 (1928).

13. Kelley, O. J., and Shaw, B. T., "Studies of Clay Particles with the Electron Microscope III—Hydrodynamic Consideration in Relation to Shape of Particles," SOIL SCIENCE SOCIETY OF AMERICA, vol. 7, p. 58 (1942).

14. Knaggs, I. E., and Lonsdale, K., "The Structure of Melamine," PROCEEDINGS, Royal Society of London, vol. 177A, p. 140, December, 1940-March, 1941.

15. Knapp, W. J., "Thermal Conductivity of Nonmetallic Single Crystals," JOURNAL, American Ceramic Society, vol. 26, p. 48 (1943).

16. Kunin, R., and Robbins, W. R., "The Relative Availability to Plants of Exchangeable Calcium from Soil Separates of Sand, Silt and Clay," SOIL SCIENCE, vol. 57, p. 137 (1944).

17. Macey, H. H., "Clay-Water Relationships and the Inner Drying Mechanism," TRANSACTIONS, British Ceramic Society, vol. 41, p. 73 (1942).

18. Miyabe, N., "Preliminary Notes on Experimental Studies on the Plastic Deformation of Soil," BULLETIN, Earthquake Research Institute, Tokyo Imperial University, vol. 14, part 4, p. 543, December 1936.

19. Morgan, W. R., "Relation Between Uncombined Quartz and Thermal Expansion of Ceramic Bodies," JOURNAL, American Ceramic Society, vol. 17, p. 117 (1934).

20. Norton, F. H., and Lawrence, W. G., "Note on Anomalous Heat Absorption of Kaolinite," JOURNAL, American Ceramic Society, vol. 26, p. 388 (1943).

21. Norton F. H., and Johnson, A. L., "Fundamental Study of Clay: V, Nature of Water Film in Plastic Clay," JOURNAL, American Ceramic Society, vol. 27, p. 77 (1944).

22. Parmelee, C. W., and Rodriguez, A. C., "Catalytic Mullitization of Kaolinite by Metallic Oxides," JOURNAL, American Ceramic Society, vol. 25, p. 1 (1942).

23. Russel, H. W., "Principles of Heat Flow in Porous Conductors," JOURNAL, American Ceramic Society, vol. 18, p. 1 (1935).

24. Russel, R., "Effect of Thermal Process on Physical Properties I, Structural Clay Products," BULLETIN, American Ceramic Society, vol. 19, p. 1 (1940).

25. Rutledge, P. C., "Neutral and Effective Stresses in Soils," PROCEEDINGS, Purdue Conference on Soil Mechanics, p. 174, July, 1940.

26. Shaw, B. T., "The Nature of Colloidal Clays as Revealed by the Electron Microscope," JOURNAL OF PHYSICAL CHEMISTRY, vol. 46, p. 1032 (1942).

27. Sheehan, J. J., "Core Shop Control," Paper No. 659, 36th Annual Conference of the Institute of British Foundrymen, June, 1939.

28. Smith, E. C. W., Roberts, A. L., and Townsend, D. T. A., "Some Fundamental Aspects of Heat Transmission from Flames and Furnace Linings," JOURNAL, Society of Glass Technology, vol. 26, p. 113 (1942).

29. Sosman, R. B., "The Properties of Silica," Chemical Catalog Company, 1927.

30. Sullivan, J. D., and Graham, R. P., "Effect of Exchangeable Bases on the Drying of Clay," JOURNAL, American Ceramic Society, vol. 23, p. 57 (1940).

31. Tanner, W. F., "An Electrical Method for the Identification of Sands," AMERICAN JOURNAL OF SCIENCE, vol. 238, p. 46 (1940).



32. Taylor, N. W., "*Reaction Between Solids Without Liquid Phase*," JOURNAL, American Ceramic Society, vol. 17, p. 155 (1943).
33. Taylor, N. W., and Cho-Yuan Lin, "*Effect of Various Catalysts on Conversion of Quartz to Cristobalite and Tridymite at High Temperatures*," JOURNAL, American Ceramic Society, vol. 24, p. 57 (1941).
34. White, H. E., and Walton, S. F., "*Particle Packing and Particle Shape*," JOURNAL, American Ceramic Society, vol. 20, p. 155 (1937).
35. Winckler, J. R., "*Spherical Furnace Calorimeter for Direct Measurement of Specific Heat and Thermal Conductivity*," JOURNAL, American Ceramic Society, vol. 25, p. 339 (1943).

## Appendices to Fourth Progress Report

1. Comments on Dilatometer Operation, by H. W. Dietert.
2. Contributions on Rate of Specimen Loading in the Hot Compressive Strength Test.
3. Investigation of Rammer Supports, by Naval Research Laboratory.

## Appendix I

### Comments on Dilatometer Operation

By H. W. DIETERT\*, DETROIT, MICH.

The following is presented in the hope that it will contribute to better dilatometer operation by those possessing such instruments.

#### SPECIMEN POSITION IN FURNACE

Length of the heat zone in the dilatometer furnace is substantially 4-in. in length and the center of this heat zone lies  $\frac{3}{4}$ -in. above the center of the furnace. Thus, it is desirable to have the refractory posts of the dilatometer of such length that the center of the sand specimen will be located  $\frac{3}{4}$ -in. above the center of the furnace, as illustrated in Fig. 10.

Refractory posts of new dimensions now are available. In these new posts, the bottom post is one-inch longer and the top post one-inch shorter than previously. This makes it easy to place the specimen in position as described above. The furnace stop collar, on the right hand support post, may be adjusted to secure the mentioned positioning.

#### QUARTZ TUBE FOR EXPANSION TEST

The present practice is to use a solid rod of quartz, silicon-carbide, or other refractory material, for measuring the volume change of a specimen in the dilatometer. A tubular member is lighter and is capable of carrying a greater load than a solid member.

By employing a heavy-walled, clear, quartz tube in place of the solid clear quartz rod, it was found that the tube was superior to the rod for the expansion test. The tube measurement of 12-mm. O.D. with 3-mm. I.D. which gives tube walls of 3-mm. is recommended in place of a solid rod.

#### THERMOCOUPLE LOCATION

Some investigators have expressed a desire to have the thermocouple inserted through the side of the furnace and through the heating element.

Tests are under way in the author's laboratory in which a thermocouple is inserted through the side of the heating element and another through the top of the furnace in the usual manner. Both couple ends are to be located at the center of the sand specimen and  $90^\circ$  apart. The side horizontal thermocouple reads  $15^\circ$  higher than the top vertical thermocouple. At present, no advantage is apparent in having a side inserted thermocouple.

\*Harry W. Dietert Co.

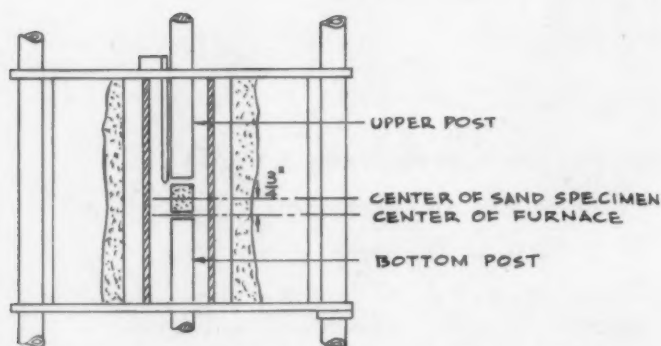


FIG. 10—RECOMMENDED LOCATION OF TEST SPECIMEN IN DILATOMETER.

The vertical couple is better protected from crushed soft sand specimens. Better protection of the thermocouple by recessing the couple wire in the insulator end is under test and promises to be a step forward.

#### ACCURACY OF HOT STRENGTH READINGS

A large number of items concerning test technique, uniformity of sand, thermal stability of the sand sample, and operation of equipment, must be under full control before consistent hot strength readings are obtainable. Sand is a very sensitive material, responding instantaneously to any change in treatment. The above applies to all sand tests; and since the temperature factor is brought into high temperature testing, the task of controlling the conditions of testing has been enlarged.

Enumerated below are some of the cautions that are to be observed in high temperature testing:

1. The sand sample should be mixed uniformly and riddled through a No. 6 mesh sieve.
2. The sand sample must be placed in an air-tight container immediately after riddling.
3. Allow the sand to temper; that is, to age after mixing, a definitely stated time. Cooling and storage time after baking also should be standardized.
4. Moisture in stored tempered sand migrates. This migration is minimized by frequent mixing in the sealed container.
5. Weighed sand samples are to be used to obtain rammed sand sampling within  $1/32$  of the 2-in. length.
6. Ends of stripping post, rammer plunger head, and dryer plates, when used, should be wiped with a cloth wetted with kerosene to avoid sand sticking to ends of the sand specimen. Ends of the sand specimen must be checked for parallelism and smoothness.
7. Turn specimen tube and stripping post  $1/2$  of a revolution

after allowing weight of rammer plunger to come to rest gently on the sand. This insures correct alignment. Then pull out the stripping post support pin.

8. Place a  $1\frac{1}{8}$ -in. diameter flat face refractory against the bottom end of the specimen. With a rotary motion of approximately  $\frac{1}{4}$  revolution, lap or seat the disk firmly to the sand specimen. Ends of the sand specimen must be flat, smooth, and free of loose sand before fitting the disk to the sand specimen. Each disk must be checked previously for flat and smooth faces. On the top end of the specimen, place a flat-convex refractory disk. Examine the flat face for flatness. Rub disk against the face of a flat grinding block to remove burnt-on sand. Make certain that the disks are on the center of the specimen and that they do not rock.

9. In the case of green sand specimens, do not ram the specimen until the furnace of the dilatometer is ready to receive the specimen.

10. At the beginning of a test run, allow the furnace of the dilatometer to remain at the chosen temperature for a period of  $\frac{1}{2}$  hr. before it is used the first time for any new chosen testing temperature.

11. Operate the dilatometer on a routine established cycle of preheating, charging furnace with sand specimen, soaking time, temperature recovery and manner of loading.

12. Clean the top of the bottom post after each test. Maintain the top of the bottom post flat by grinding the end of the post against a disk grinder.

13. A sand specimen with the disks in place must not rock. Insert the sand specimen and the disk in place on the bottom post of the dilatometer with a pair of tongs having circular grips shaped to pick up bottom disk and sand specimen with one operation.

14. A uniform loading table rise of 1-in. per min. which may be obtained by turning the hand crank  $\frac{1}{2}$  revolution per second, and is automatically obtained with motor operated dilatometer, gives satisfactory results for all molding materials tested to date.

15. Molding materials that spall and crack badly when the dilatometer furnace at high temperature is lowered around them, are likely to give erratic hot strength readings, since they do not crack the same way or amount from one specimen to the next. It is recognized that such materials, including sand that spalls, are of inferior quality and should receive some preliminary treatment to make them thermally stable.

Some sands reduce in all strengths, such as green, dry, and hot, on storage. To show the effect of storage on the hot strength of one of these sands, the following test results obtained on green sand specimens are of interest:

<i>Tested Shortly After Mixing</i>	<i>Tested 24 hours After Mixing</i>
177—2000-12-G	138—2000-12-G
178	126
173	148
165	123
<hr/> 173 Average	<hr/> 133 Average

When carefully executed, standardized routine operations are followed in high temperature testing, one obtains consistent test results such as tabulated below for a thermally stable sand:

63—2500-12-G  
63  
66  
63  
60

However, any deviation from the above program results in erratic results, just as are obtained in a foundry making good and bad castings, seemingly from the same sand. High temperature testing is a good teacher for foundry-men, because it shows, from a casting standpoint, that the term "same sand" means little if we disturb a proven routine cycle of operation.

#### CORRELATION OF A.F.A. 2 x 2-IN. WITH $1\frac{1}{8}$ x 2-IN. SPECIMEN READINGS

It has been the desire of several research workers to find some way of correlating the permeability and strength readings of the  $1\frac{1}{8}$  x 2-in. double-end rammed sand specimen with that of the A.F.A. 2 x 2-in. single-end rammed specimen.

The  $1\frac{1}{8}$  x 2-in. specimen, rammed with the three drops of a 7-lb. weight falling  $2\frac{3}{8}$  in. and employing a floating specimen tube during the ramming operation, is rammed more uniformly and of a greater mold hardness than is the A.F.A. 2 x 2-in. specimen.

To cause the test readings of the  $1\frac{1}{8}$ -in. diameter specimen to be similar to those obtained from the A.F.A. 2-in. diameter specimen, all that is necessary is to reduce the ramming energy used on the former to produce specimen of substantially the same mold hardness, density and of about the same degree of non-uniformity of hardness as obtained in a 2-in. diameter specimen. This sacrifice in uniformity may be well worthwhile to make it easier to correlate test results of the different specimens.

When the  $1\frac{1}{8}$ -in. diameter sand specimen is rammed with 2 drops, in place of 3 drops of the 7-lb. weight, permeability and green compression readings obtained from the A.F.A. 2-in. diameter and the  $1\frac{1}{8}$ -in. diameter specimens are identical, for all practical purposes.

Comparative test data obtained from the standard A.F.A. specimen and the  $1\frac{1}{8}$ -in. diameter specimen, as used in high temperature testing, are shown in Table 7. The data shown are of a special selected group of sands covering



Table 7  
GREEN SAND TEST DATA OBTAINED ON A.F.A. 2x2-IN. AND 1/8x2-IN. SPECIMENS

Sample Number	Sand	Moisture, per cent	Flowability, per cent	Permeability, 1/8-In. Dia.		Compression, lb.		Density, 1/8-In. Dia.		Mold Hardness, A.F.A. 2-In.			Mold Hardness, 1/8-In. Dia.		
				A.F.A.	Dia.	A.F.A.	Dia.	A.F.A.	Dia.	Top	Center	Bottom	Top	Center	Bottom
1	96 Per Cent Ottawa W&D	2.0	82	223	235	5.05	5.025	1.573	1.608						
2	4 Per Cent Bentonite														
	2 Per Cent Cereal														
3	94 Per Cent Ottawa W&D	2.8	72	245	227	6.2	6.3	1.544	1.583						
	4 Per Cent Bentonite														
	2 Per Cent Cereal														
4	84 Per Cent Ottawa W&D	4.9	69	175	180	8.4	8.15	1.631	1.650						
	4 Per Cent Bentonite														
	2 Per Cent Cereal														
	10 Per Cent Silica Flour														
5	74 Per Cent Ottawa W&D	5.8	62	115	120	9.15	9.45	1.662	1.698						
	4 Per Cent Bentonite														
	2 Per Cent Cereal														
	20 Per Cent Silica Flour														
6	Albany no. 1 1/2	7.2	70	7	5	14.9	15.9	1.636	1.667						
7	South Amboy	1.8	84	402	310	.91	.55	1.699	1.709						
8	Millville Gravel	5.2	65	326	273	17.85	19.0	1.670	1.642						
9	Albany 3M.	6.8	80	32.3	30.5	8.45	6.9	1.719	1.725						
10	Taggart no. 1 1/2	6.2	74	79.2	67.5	9.8	9.6	1.602	1.709	82	76	70	85	79	82
11	Pink Seal	7.5	76	20	17.3	9.95	9.7	1.65	1.667	83	78	68	79	73	77
12	Gold Seal	5.4	80	12.7	10.5	8.975	8.6	1.573	1.588	80	72	72	78	72	78
	Lumberton	6.0	71	18.1	15.3	14.55	15.8	1.631	1.746	88	85	83	88	85	88

extremes in physical properties. A good practical correlation is obtained in all cases except for sand samples 6 and 7. Here is the extreme in green compression strength, sample 6 with 0.91 psi. and sample 7 with 17.85 psi. Sample 6, with its low strength, has a high flowability of 84 per cent, while sample 7, with its high strength, has a low flowability of 65 per cent. These wide variances caused the permeability of the 2-in. and the  $1\frac{1}{8}$ -in. diameter specimens to check poorly. However, these two good sands first would be blended before being used in the foundry so that, from an operating standpoint, this inability of the two specimens to check is not too detrimental.

Figures 11 and 12 show the correlation between permeability and green compression strength of the two specimens when the  $1\frac{1}{8}$ -in. diameter specimen is rammed with two blows of the rammer.

In summarizing, it may be stated that, from the information at hand, it seems desirable to change the number of rams from three to two drops for the  $1\frac{1}{8} \times 2$ -in. specimen so that practical correlation may be obtained between the two sized specimens. Additional test work should be undertaken at an early date to add to our present knowledge on this particular question.

#### FURNACE TEMPERATURE

The physical properties of a foundry sand are instantaneously affected by elevated temperatures. Any change in temperature is easily noted on the hot strength and, since it takes time for the heat (temperature) to penetrate into the sand mass, the time of heat application is very critical.

A good illustration of the rapidity of sand change when subjected to a

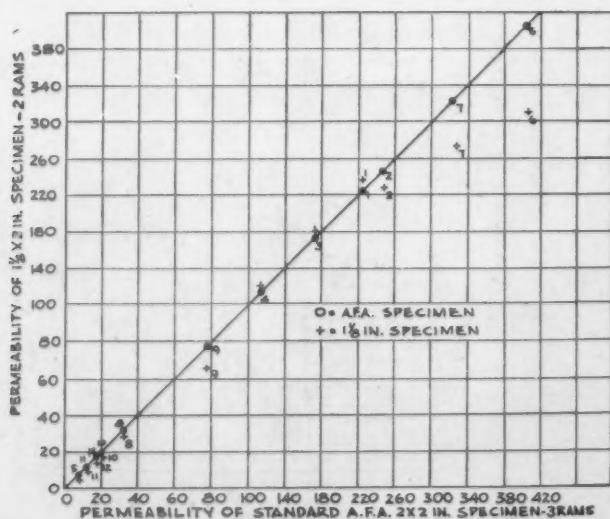


FIG. 11—RELATION BETWEEN PERMEABILITY READINGS ON 2 X 2-IN. STANDARD A.F.A. SPECIMEN RAMMED WITH THREE DROPS OF STANDARD RAMMER AND THOSE OBTAINED ON THE  $1\frac{1}{8} \times 2$ -IN. SPECIMEN RAMMED WITH TWO DROPS OF ITS PROPER RAMMER.

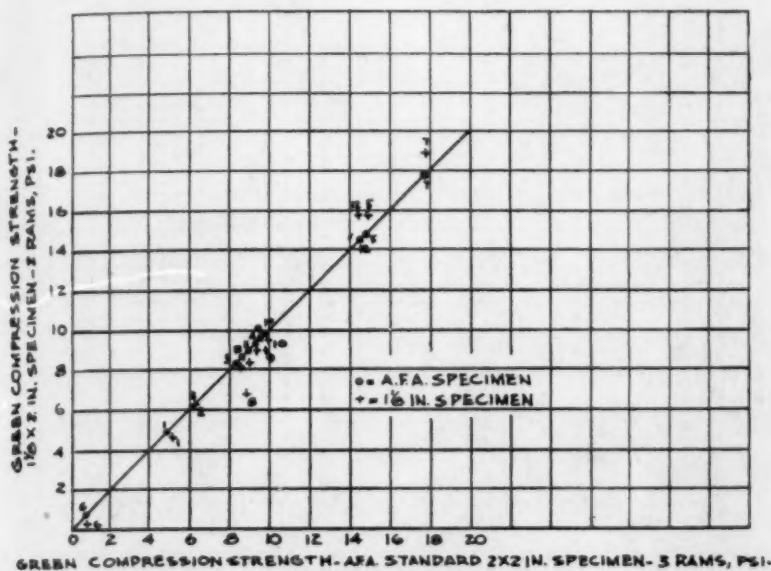


FIG. 12—RELATION BETWEEN GREEN COMPRESSION STRENGTH ON THE SAME SPECIMENS AND SAME RAMMING CONDITIONS AS FIG. 11.

temperature of 2500° F. is found in Fig. 13. The hot strength developed by both a green and dry sand is shown from zero to 12 min. soaking time in a temperature of 2500° F.

The sand composition was:

74 per cent	no. 17 Ottawa washed and dried sand
20 per cent	Silica flour
4 per cent	Bentonite
2 per cent	Cereal
5.5 per cent	Water

Referring to Fig. 13, both the green and dry compression strengths of the sand are shown at zero time. The dry sand loses strength from 260 to 30 psi. in the first minute. This can be described as a reduction of the dry strength to hot strength. Then, from one to two min. soaking, the hot strength increases from 30 to 70 psi. which the writer wishes to describe as "pyro strength." The pyro strength increases with an increase of fine siliceous material, for example, silica flour. When no fine siliceous material is present, no pyro strength is noted. The hot strength decreases on heating, usually to a soaking period of 3 to 4 min. After a soaking period of from 3 to 4 min., when fine siliceous material is present, as is the case of the sand in Fig. 13, the hot strength increases on continued heating for extended periods into hours.

The development of hot strength for a green sand is similar to that of

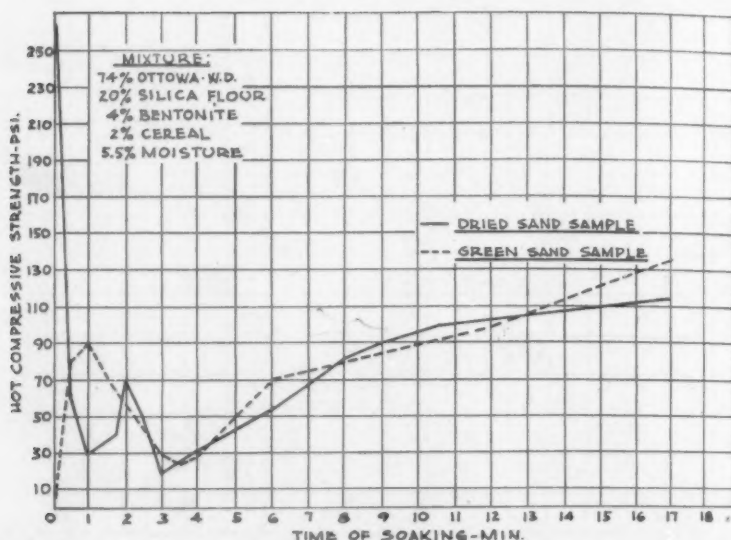


FIG. 13—EFFECT OF SOAKING TIME ON HOT STRENGTHS DEVELOPED IN GREEN AND DRY SAND SPECIMENS AT 2500° F.

a dried sand, with the exception that there is a rapid rise in strength the first 30 sec. of heating. Referring to Fig. 13, it may be noted that the green strength of 6 psi. is converted to a hot strength of 78 psi. the first 30 sec. This explains why it is possible in the foundry to use green sand molds for many heavy-section castings because the heat of the metal will immediately produce a high hot strength on the face of a green sand mold. In many sand mixtures, this initial hot strength exceeds the hot strength produced by a longer soaking time.

#### FURNACE PREHEAT TEMPERATURE

Data has been presented showing the importance of soaking time on a sand specimen at a given temperature. It is evident that the furnace temperature must be maintained at a definite chosen temperature during the chosen soaking time. The furnace temperature will drop when the heating unit is raised and then lowered around a cold sand specimen and the cooled bottom post.

One method of operating the furnace is to have the pyrometer controller set at the temperature of test, for example, 2000° F. The furnace is raised, specimen inserted and furnace is lowered in an established 7-sec. time interval.

The voltage on the heating element of the furnace is so adjusted that the furnace will recover to the chosen test temperature at a definite time interval, for example, 6 min. This test method is designated as method A.

#### ANOTHER OPERATION METHOD

Another method of operation is to anticipate the furnace temperature drop during which the specimen is being inserted. This temperature drop is deter-

mined by trial runs in which the furnace temperature is raised a certain amount above the test temperature. For example, assume the test temperature is to be 2000° F. When the furnace is preheated to 2200° F., just prior to inserting the specimen, it is found that the furnace temperature will drop to 2000° F. after the specimen has been inserted and the furnace lowered. In such an instance, subsequent to each loading, the furnace is preheated to 2200° F. A furnace test temperature of 2000° F. is obtained immediately the soaking period starts and is easily maintained at that value throughout the soaking time cycle. This seems to be the correct manner of temperature control, since the specimen is subjected during the entire soaking time to the chosen test temperature. This is to be known as Method B.

To illustrate the importance of standardization on some manner of temperature control, the following data serves:

<i>Method A</i>	<i>Method B</i>
6 Minute Temperature Recovery	Furnace Preheated
164—2000-12-G	187—2000-12-G
152	182
165	175
Avg. 160	181

A disadvantage of test Method B is the time lost in preheating and the fact that the additional preheated temperature subtracts from the life of the thermocouple. To eliminate these disadvantages, a new short upper post has been developed which is held in a bracket mounted on top of the furnace. A steel guide post passing through the top cross bar retains the present rigidity of the upper post. This new short upper post is grooved to receive the thermocouple which gives improved protection to the couple. An air-tight seal also is obtained at the top of the furnace, which stops the air current through the furnace and increases the length of the hot zone.

With this method of mounting, which may be readily attached to any dilatometer not so equipped, the furnace is not cooled by raising it to the upper position. The degree of superheat required is less than 50° when operating at 2500° F. Thus, for plant control work, one could neglect the preheating cycle, since the furnace will recover the 50 degree drop quickly. However, in research tests, the Method B of preheating sufficiently to drop exactly to the chosen temperature, after the specimen has been inserted in the furnace, is recommended.

## Appendix II

### Contributions on Rate of Loading of Specimen in the Hot Compressive Strength

TEST DATA COLLECTED BY H. RIES\*, ITHACA, N. Y.

In making the hot strength test, the load may be applied by a motor driven device, or a hand operated one.

The former, it is assumed, applies the load at a regular rate. In the latter case, the pressure is applied by means of a hand operated crank, and while this can be turned at a uniform speed, the rate of application of load will depend on whether it is turned slowly or rapidly and it has not been demonstrated as yet which rate is desirable.

Some tests which have been made indicate that, with few exceptions, the sand shows a higher hot strength if the load is applied rapidly.

It may be of interest therefore to give a few sets of figures.

*Test Series 1* (Table 8)—By L. B. Osborn, Hoagland and Hardy Co., Evansville, Ind. Test basis—Soaking time, 5 min.; temperature, 2000° F.; 2 x 2-in. specimens. It will be noticed from the data in Table 8 that in eight cases out of ten more rapid application of load produced a variable increase in the hot strength. In two cases the hot strength was less.

**Table 8**  
**HOT COMPRESSIVE STRENGTH RESULTS**

<i>Molding Sand</i>	<i>Motor Drive, 2.06 lb. per sec.</i>	<i>Hand Operation</i>	<i>Time, Hand Operation</i>
1.	24	34	2
2.	53	104	5
3.	122	128	6
4.	162	164	13
5.	42	52	3
6.	58	90	8
7.	214	150	7
8.	122	126	5
9.	176	100	4
10.	86	96	5

*Test Series 2* (Table 9)—By R. H. Gowen, General Electric Co., Everett, Mass. The mixture contained 21.51 per cent silica flour, 0.84 per cent bentonite, and 1.24 per cent core oil. The remainder was sand with a fineness of 30-40. The samples were soaked for 8 min. at 2500° F.

\*Technical Director, Foundry Sand Research Project.



**Table 9**  
EFFECT OF RATE OF LOADING

$\frac{1}{2}$ Turn per Second		2 Turns per Second	
Time to Break Sample, Sec.	Hot Strength, psi.	Time to Break Sample, Sec.	Hot Strength, psi.
45	122	14	175
38	121	12	228
35	137	11	211
42	118	11	200
42	107	11	197

*Test Series 3*—By H. W. Dietert, Harry W. Dietert Co., Detroit, Mich. Mr. Dietert claims that this series of tests illustrates how sensitive bentonite-bonded sands are to the rate of loading when in the plastic range, as for example 2000° F. His figures are shown in Table 10.

**Table 10**  
EFFECT OF RATE OF LOADING

30 rpm., psi.	Per Cent Variation from Average	60 rpm., psi.	Per Cent Variation from Average
175	2.77	270	2.2
175	2.77	235	14.55
200	11.10	272	1.5
175	2.77	328	18.8
176	2.70	260	5.8
Avg. 180		Avg. 276	

It seems that even these few sets of figures emphasize the fact that a uniform rate of loading should be adopted. What that rate is still remains to be proved.

The figures of R. H. Gowen were obtained on a core mixture which contained very little bentonite; yet they show appreciable differences.

## DISCUSSION

H. W. DIETERT (*written discussion*): Hot strength test data between different dilatometer units testing synthetic sand mixtures made on different days may be made to check very closely when the operators observe good sand testing technique in the mixing, preparation of the sand specimen, furnace temperature control, and use an agreed upon table rise per minute, for example—one inch per minute, to obtain an identical load application to the specimen.

To illustrate that good test results may be obtained, Table 11 shows hot strength data obtained from two dilatometer units, designated *A* and *B*. The dilatometer unit *A* is hand operated while unit *B* is motor driven.

It may be noted that good reproducibility is obtained for each series of tests and that dilatometer unit *B* test data is from 0.9 to 8.0 per cent lower than results obtained from dilatometer unit *A*. Considering the sensitiveness of the physical properties of foundry sands, these hot strength tests are equal to accuracies that are obtained in strength tests at room temperatures.

Table 11

HOT COMPRESSION STRENGTH OF A SAND MIXTURE DETERMINED  
ON TWO DILATOMETER UNITS

*Test Conditions*—Hot Strength at 2000° F., 12 min. soaking period; rate of table rise, one inch per min.; recovery, 4½ min.

<i>Unit A,</i>	<i>Unit B,</i>
<i>psi.</i>	<i>psi.</i>
117	113
117	108
112	93
120	110
	112
Average 116.5	107.2
Max. Variation from Average 3.0 per cent	13.2 per cent
Difference between A and B 8.0 per cent	

*Check Test Three Days Later*

<i>Unit A</i>	<i>Unit B</i>
118	100
120	103
120	118
108	108
118	110
Average 117	108
Max. Variation from Average 7.6 per cent	7.4 per cent
Difference between A and B 7.7 per cent	

*Increase Voltage input by 2 volts, recovery time, 3¼ min.*

<i>Unit A</i>	<i>Unit B</i>
112	110
118	108
113	110
118	108
Average 115 psi.	109 psi.
Max. Variation from Average 2.6 per cent	0.9 per cent
Difference between A and B 5.1 per cent	

TEMPERATURE GRADIENTS IN FURNACE

The temperature gradient found within the hollow tube forming the silicon-carbide heating element of the furnace, is very good when the air circulation through the furnace is eliminated by a refractory collar seal around the upper post at the top of the furnace. A short upper post also adds to the uniformity of the temperature within the furnace at the central working position.

Figure 14 shows a temperature traverse obtained in a furnace with a short upper post and equipped to eliminate air-flow. The levels above and below the center of the test specimen at which temperature readings were taken, also is shown, as well as the readings themselves.

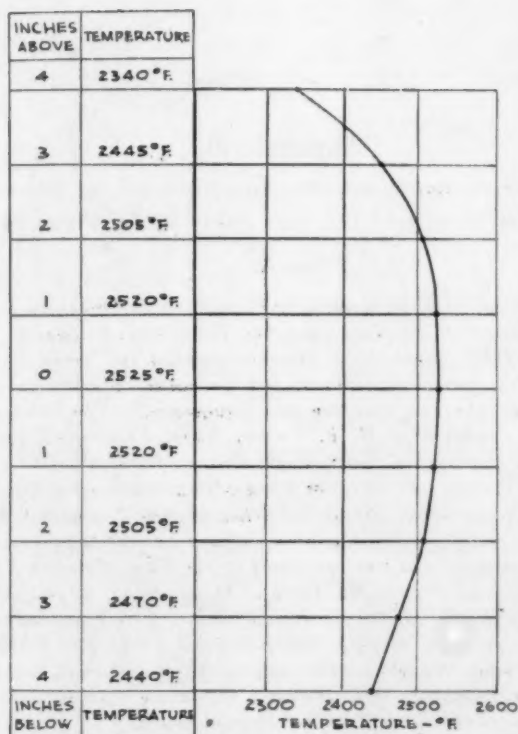


FIG. 14—TEMPERATURE TRAVERSE OBTAINED IN A DILATOMETER FURNACE EQUIPPED WITH SHORT UPPER POST OF MULFRAX MATERIAL AND REFRACTORY COLOR SEAL TO REDUCE AIR FLOW IN FURNACE.

The length of the sand specimen is 2 in. so that a uniform temperature zone with a length of 4 in. is ample. The maximum temperature within this 4-in. length zone for a controlling temperature setting of 2500° F., is 20° F. or 0.8 per cent. The maximum variation within the zone in which the sand specimen is located is 5° or 0.2 per cent. This is excellent furnace performance at elevated temperatures.

## Appendix III

### REPORT OF SUB-SUBCOMMITTEE ON RAMMER SUPPORTS OF SUBCOMMITTEE ON PHYSICAL PROPERTIES OF STEEL FOUNDRY SANDS AT ELEVATED TEMPERATURES

#### Abstract

*At a meeting of Subcommittee 6b7 on Physical Properties of Steel Foundry Sands at Elevated Temperatures in Chicago, October 21, 1943, Chairman Finster appointed a sub-subcommittee to "investigate and standardize the method of ramming test specimens and of checking and standardizing tube and stripping post equipment." The sub-subcommittee was composed of H. F. Taylor, Naval Research Laboratory, Washington, D. C., Chairman; H. W. Dietert, Harry W. Dietert Co., Detroit; E. Pragoff, Jr., Hercules Powder Co., Wilmington, Del.; and D. C. Williams, A.F.A. Research Fellow, Cornell University, Ithaca, N. Y. This report summarizes the work done by the sub-subcommittee on rammer supports and was performed at the Naval Research Laboratory under the direction of Mr. Taylor. In this study, various methods of supporting the A.F.A. Standard sand rammer were examined to find their effects on sand strength and permeability. It was found that shock absorbing supports were unsatisfactory. Several acceptable methods are described. Mr. Williams is making further studies on the specimen tube which will not be reported herein.*

#### HISTORICAL BACKGROUND

There has been considerable discussion regarding the cause of variations in sand test results between various laboratories when an attempt is made to check techniques. One of the conditions suspected of causing variable results is the foundation of the sand rammer. It is agreed generally that it should be as solid as possible but laboratories differ in their interpretation of the degree of solidity necessary. Interest in standardizing all testing methods is particularly acute at this time because of the recent work of testing sands at elevated temperatures.

#### *Types of Rammer Supports*

At the Naval Research Laboratory, one rammer is mounted on a cast iron pedestal and the other is mounted on an 8-in. wooden post, both extending down to the concrete floor. Another laboratory uses a 1 x 18 x 22-in. steel plate which rests near the center of a large table. Concrete or wooden posts are frequently used for foundations, while some rammers are secured to a table directly over one leg. On the underside of the rammer base is a box which is designed to make good contact with the supporting foundation. It

has been noted, however, that in some cases, the boss is not in a plane with the feet at the corners of the rammer. Consequently, if the rammer is placed upon a flat surface, it will be supported only at the corners and will give a springy reaction.

#### *Variations in Technique*

Variations also are possible in the method by which the weight is raised and dropped. On rammers equipped with cams and cranks, the speed at which the crank is turned, and the way it is manipulated, seem to affect the results. On rammers without cranks, variations result from the manner in which the operator holds and releases the weight. Unless the hands are removed quickly they will absorb some of the energy of the drop. These, however, are variables which can be standardized readily for any given laboratory.

#### EXPERIMENTAL PROCEDURE

To determine the importance of securely mounting the rammer, a series of tests was made. As a preliminary step, the bottom on the rammer was machined flat and scraped to match a surface plate. It was decided to mount the rammer on several types of foundations, including one with shock absorbers, and to place steel blocks of various weights between the rammer and the shock absorbers to see if it is possible to have a large enough reaction block to deliver all of the ramming energy to the specimen, regardless of the springiness of the foundation.

#### *Mixture Used*

A 200-lb. batch of sand was mixed, containing 188 lb. of washed silica sand, 10 lb. of western bentonite, 2 lb. of corn flour binder and approximately 4 per cent water. This was mixed for one minute dry and mulled for 5 min. wet. It was then screened through a  $\frac{1}{4}$ -in. mesh screen, placed in a 10-gal. galvanized can with a tight fitting cover, and left to temper overnight.

Before starting tests the next morning, the sand was stirred in the can and a small amount removed and screened again. This was placed in a gallon jar which was sealed immediately. Each series of tests consisted of ten determinations of green permeability and green compressive strength. The weight of the specimen also was recorded. A slight correction was made when necessary on the weight of the second or third specimen. Figures 15 to 32 show the apparatus used and the green permeability and green compressive strength. In each of the 18 figures, the last line of the data shown is the average of the ten tests.

#### DISCUSSION OF RESULTS

Series 1 to 6 (Figs. 15 to 20 inclusive) were made with the rammer resting on a spruce board 1 x 12 x 60 in., which was supported at each end by a brick, so that the unsupported length was 52 in. In Series 1, the rammer base was clamped directly to the board as shown in Fig. 15. In Series 2 to 6, addi-

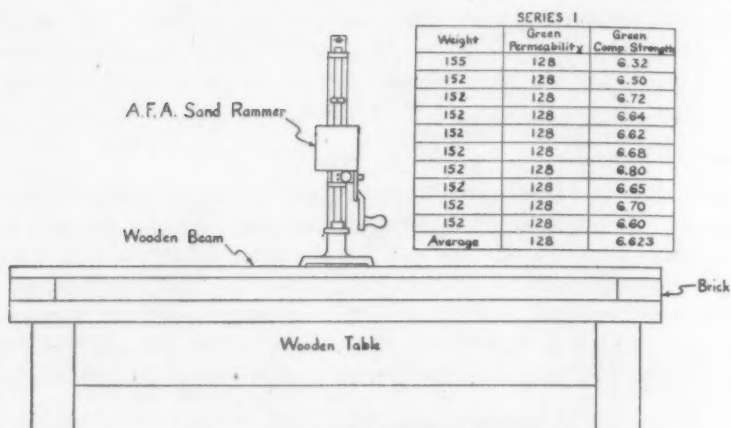


FIG. 15—A.F.A. SAND RAMMER MOUNTED ON WOODEN BEAM.

tional weights were added between the base of the rammer and the board, as shown in Figs. 16 to 20, inclusive.

It was thought that it might be possible to add enough mass so that energy from the drop weight would all be transferred to the specimen. The average of these six series of tests show that with 166 lb. underneath the rammer, compressive strength values are still lower than for a solid foundation. Since green compressive strength seems to be the most sensitive test, the results of this test will be discussed instead of density and green permeability. These values also are reported in the tables, for general interest.

#### First Test Series

Series 7 (Fig. 21) shows the results of placing the rammer on the concrete

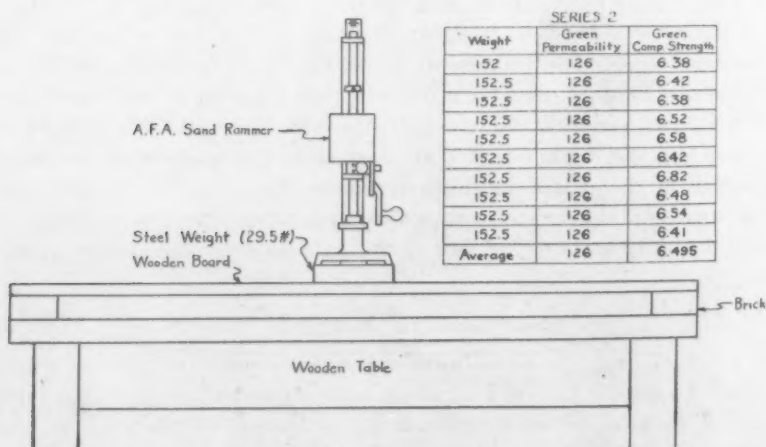


FIG. 16—A.F.A. SAND RAMMER MOUNTED ON WOODEN BEAM WITH 29.5-LB. REACTION BLOCK



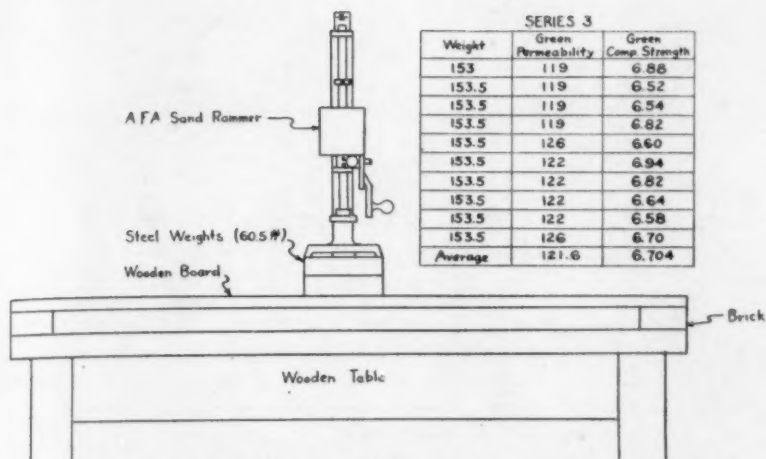


FIG. 17—A.F.A. SAND RAMMER MOUNTED ON WOODEN BEAM WITH 60.5-LB. REACTION BLOCK.

floor. The weights were placed under the rammer, but at this time no method was available for fastening the assembly to the floor. The average green compressive strength was 7.244 psi. The last figure has little significance and is retained only for computing per cent deviation from the average results. Extrapolating the curve shown in Fig. 33 to intersect the strength value produced by placing the rammer on the concrete floor, indicated the possibility that placing weights totalling 250 lb. under the rammer base might give results equal to those produced when the rammer was placed on the concrete floor. In later tests, this did not prove to be the case.

As an alternative to the board, a group of rubber shock absorbers was placed

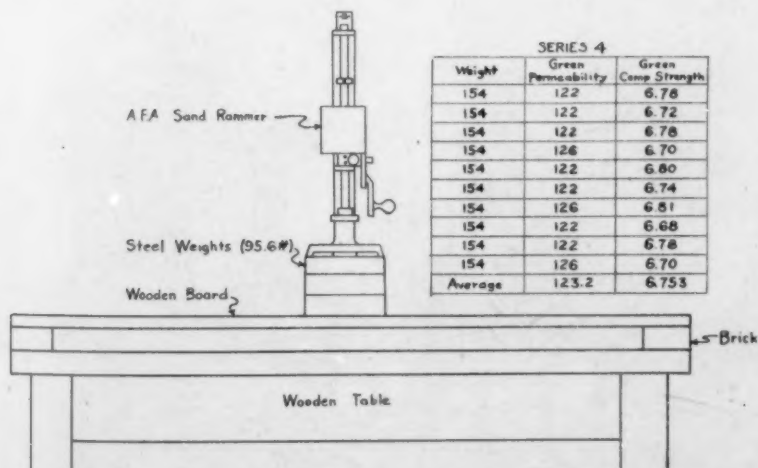


FIG. 18—A.F.A. SAND RAMMER MOUNTED ON WOODEN BEAM WITH 95.6-LB. REACTION BLOCK.

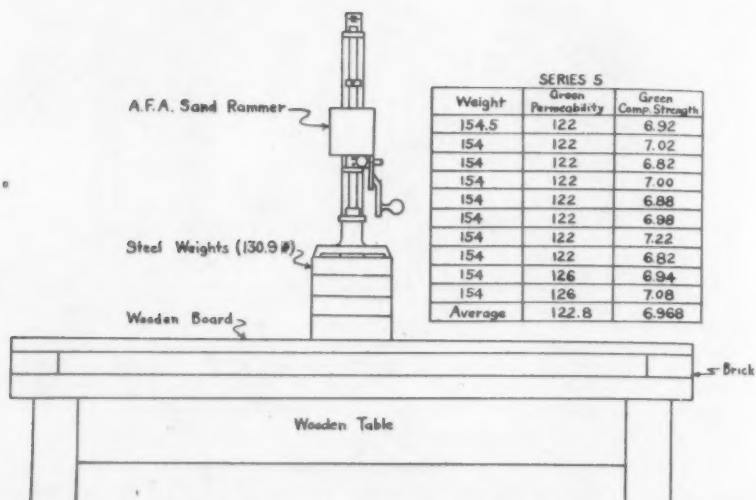


FIG. 19—A.F.A. SAND RAMMER MOUNTED ON WOODEN BEAM WITH 130.9-LB. REACTION BLOCK.

under a stack of five weights as shown in Fig. 22. The green compressive strength produced in this case was 6.962 psi. A similar arrangement was tried with only one weight between shock absorbers and the base of the rammer. It is shown in Fig. 23. This mounting produced a green compressive strength of 6.866 psi. Thus, it is seen that even with a weight of 166 lb., maximum compressive strength can not be developed on shock absorbing devices.

Series 10 (Fig. 24) shows the effect of placing the rammer on the iron

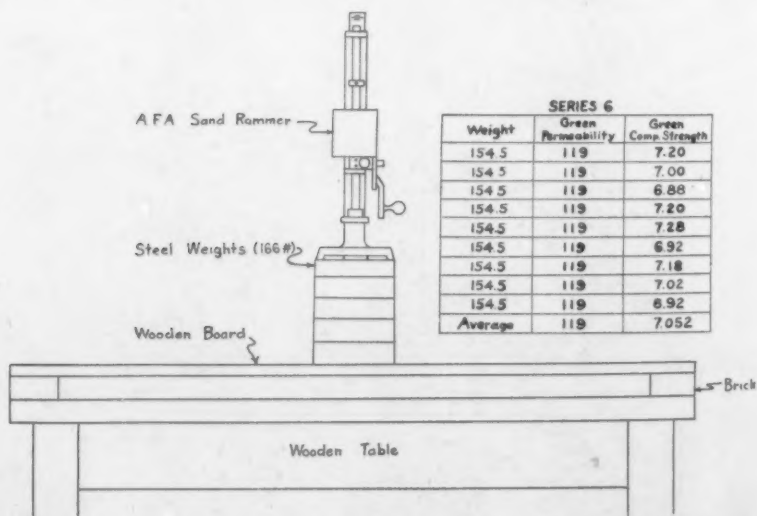


FIG. 20—A.F.A. SAND RAMMER MOUNTED ON WOODEN BEAM WITH 166.0-LB. REACTION BLOCK.

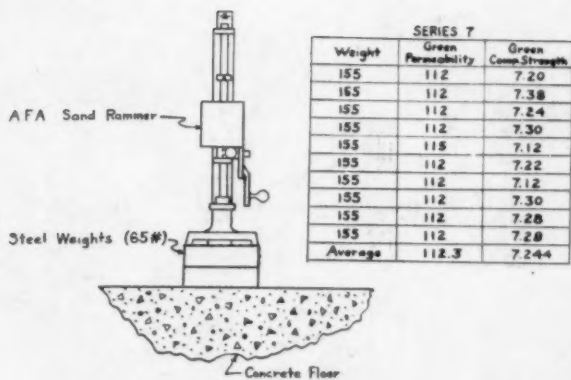


FIG. 21—A.F.A. SAND RAMMER MOUNTED ON CONCRETE FLOOR.

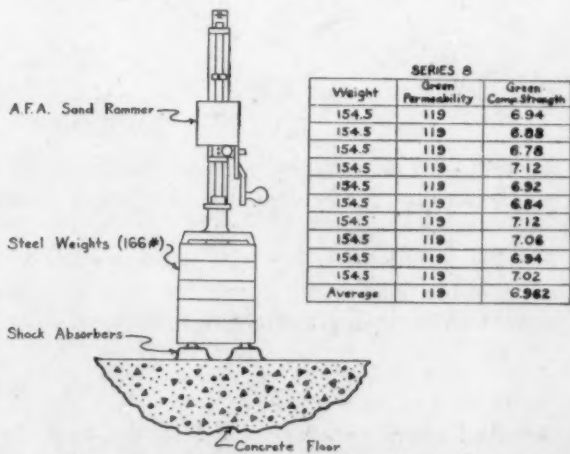


FIG. 22—A.F.A. SAND RAMMER MOUNTED ON SHOCK ABSORBERS WITH 166.0-LB. REACTION BLOCK.

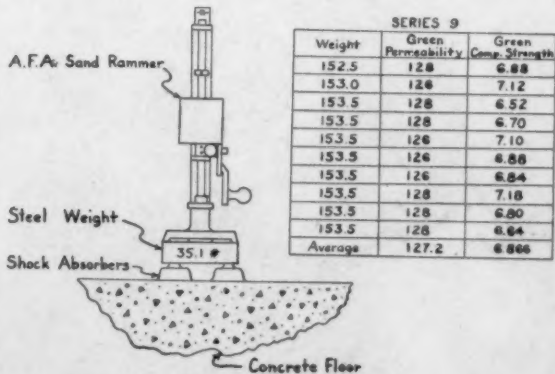
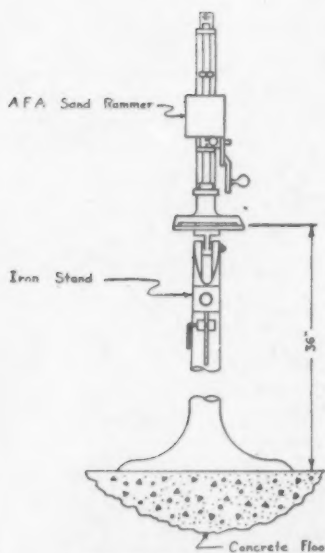


FIG. 23—A.F.A. SAND RAMMER MOUNTING ON SHOCK ABSORBERS WITH 35.1-LB. REACTION BLOCK.



SERIES 10		
Weight	Green Permeability	Green Comp. Strength
155	115	7.18
155.5	112	7.52
155.5	115	7.38
155.5	115	7.18
155.5	115	6.80
155.5	115	7.30
155.5	115	7.20
155.5	115	7.10
155.5	115	7.12
155.5	115	7.58
Average	114.7	7.236

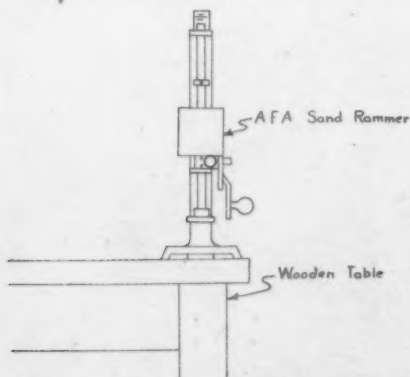
FIG. 24—A.F.A. SAND RAMMER MOUNTED ON IRON STAND.

stand which has been used here for several years. The strength produced was 7.236 psi. This checks very closely with that produced with the rammer on the floor.

Series 11 (Fig. 25) includes only five tests and was made with the rammer fastened to the top of the table over one leg. The table top was a 2-in. plank, and the legs were 4 x 4-in. square and about 30-in. long. The strength produced was 7.294 psi.

#### Second Test Series

The tests described above were completed on the same day. Two days later, seven more series of tests were run which were made on the same batch



SERIES 11		
Weight	Green Permeability	Green Comp. Strength
154.5	115	7.22
155	115	7.42
155	115	7.28
155	115	7.30
155	115	7.25
Average	115	7.294

FIG. 25—A.F.A. SAND RAMMER MOUNTED ON CORNER OF WOODEN TABLE, 1ST DAY.

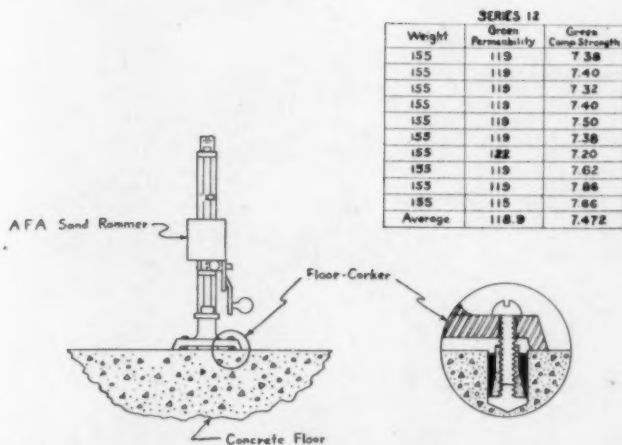


FIG. 26—A.F.A. SAND RAMMER MOUNTED ON FLOOR AND SECURED WITH CORKERS.

of sand, but the results are not necessarily comparable to those from the tests described above because the sand had two additional days to temper. The first of these tests, Series 12 (Fig. 26), was made with the rammer fastened to the concrete floor by small expansion shields called corks. Care was taken to select a very flat area on the concrete. The strength produced was 7.472 psi.

Series 13 (Fig. 27) was made with the rammer placed on rubber shock absorbers with weights totalling 261.7 lb. The strength produced was only 7.138 psi., which is well below that produced by a rigid support.

In Series 14 (Fig. 28), the rammer was placed on a wooden foundation consisting of a cylindrical post of 8-in. diameter and 38-in. high, to the top

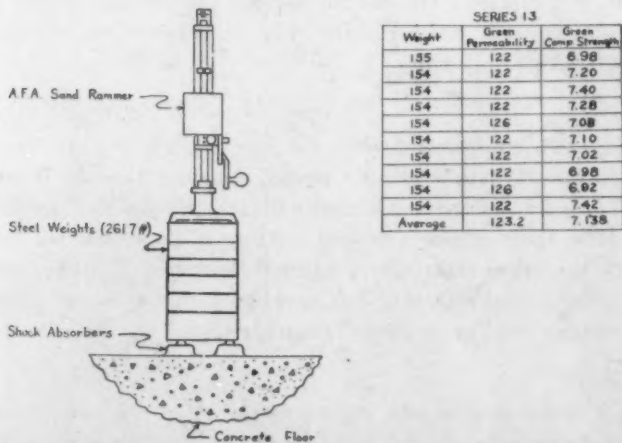


FIG. 27—A.F.A. SAND RAMMER MOUNTED ON SHOCK ABSORBERS WITH 261.7-LB. REACTION BLOCK.

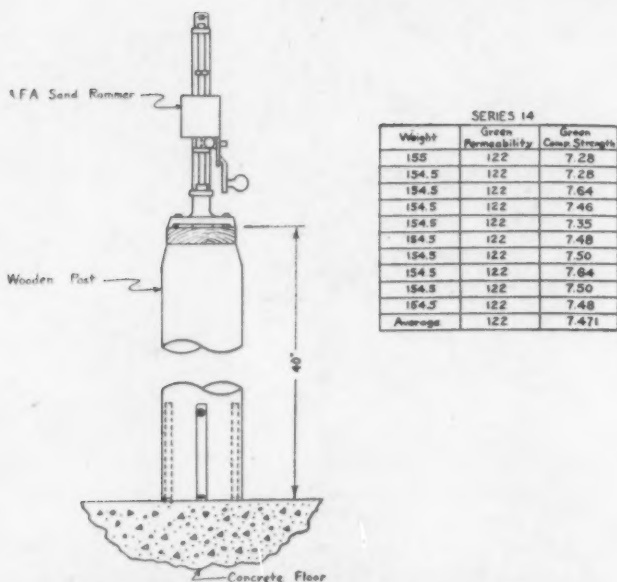


FIG. 28—A.F.A. SAND RAMMER MOUNTED ON WOODEN POST.

of which was fastened an oak block 2 x 7 x 10-in. The post was fastened to the floor and the rammer secured to the top. The strength produced was 7.471 psi., which is almost identical with that produced when the rammer was on the concrete floor.

The tests on the iron stand were made by two different operators and are shown as Series 15 and 16 (Figs. 29 and 30) and in Table 12. The strength of the specimens made by the first operator was 7.368 psi., while that produced by the second was 7.489 psi., a difference of 0.121 psi. The average of these results is 7.428 psi. The deviation from the average is 0.06 psi. and the per cent deviation is 0.8 per cent. This is believed to be satisfactory agreement for tests of this type.

### Third Test Series

To give the shock absorbing devices the best possible test, it was decided to run one more series with a heavier weight than had been used previously. The board was used as before and loaded with steel blocks with weights totaling 328 lb. The rammer was clamped on top of these and ten tests were made in which the green compressive strength averaged 7.210 psi., as shown in Series 17 (Fig. 31). From this it is concluded that it is not practical to use shock absorbing devices or other non-rigid supports.

### Fourth Test Series

For the final series of tests, the corner of the table was sanded to a very flat surface and the rammer clamped tightly to it. These tests, Series 18



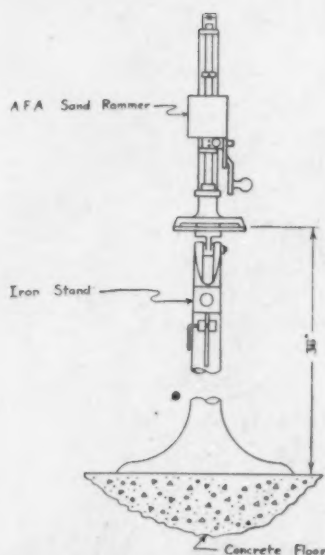


FIG. 29—A.F.A. SAND RAMMER MOUNTED ON IRON STAND, 1ST OPERATOR.

SERIES 15		
Weight	Green Permeability	Green Comp Strength
154.5	126	7.22
154	126	7.42
154	122	7.34
154	126	7.46
154	126	7.50
154	126	7.24
154	126	7.36
154	126	7.42
154	126	7.42
Average	125.6	7.368

(Fig. 32), produced a green compressive strength of 7.526 psi. The average results from the 18 series described above are shown on Table 12.

#### COMPARISON OF TEST RESULTS

Since these tests were made on different days, those made the first day

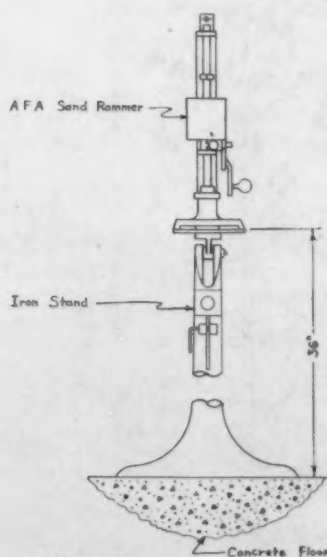


FIG. 30—A.F.A. SAND RAMMER MOUNTED ON IRON STAND, 2ND OPERATOR.

SERIES 16		
Weight	Green Permeability	Green Comp Strength
154	126	7.48
154	126	7.52
154	126	7.52
154	126	7.43
154	126	7.51
154	126	7.56
154	126	7.52
154	126	7.47
154	126	7.45
154	126	7.43
Average	126.2	7.489

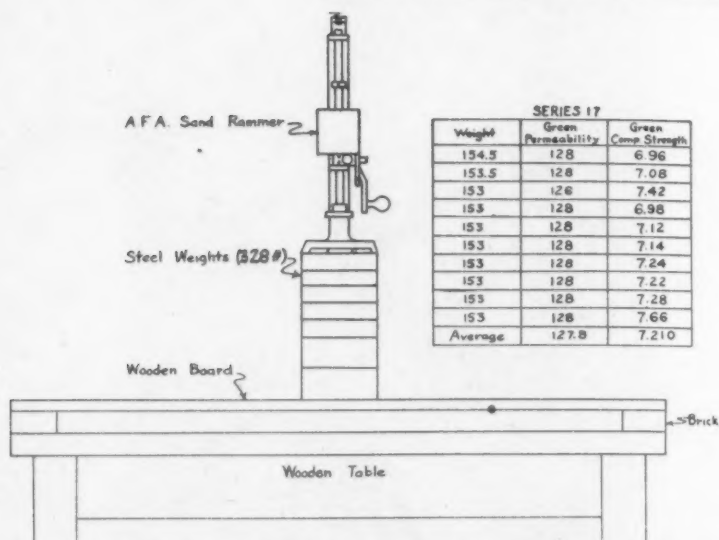


FIG. 31—A.F.A. SAND RAMMER MOUNTED ON WOODEN BEAM WITH 328-LB. REACTION BLOCK.

are not comparable to those made two days later. To form a basis for comparison, it was decided to average the results of tests made on the rigid supports for each day separately. The individual results for each day then may be discussed as percentage deviations from the average for that day. This information is shown in Table 13. The green compressive strength is 0.207 psi. higher on the second day than on the first. The maximum deviation from the average was 1.30 per cent and the average deviation from the average only 0.45 per cent.

### CONCLUSIONS

From this work, the following conclusions may be drawn:

1. Between specimens rammed on rigid and non-rigid supports,

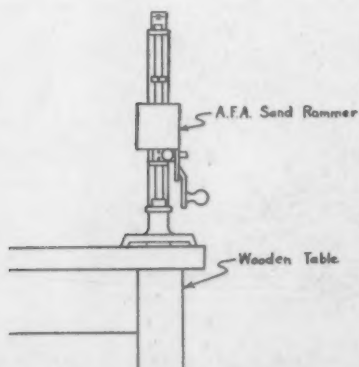


FIG. 32—A.F.A. SAND RAMMER MOUNTED ON CORNER OF WOODEN TABLE, 2ND DAY.

Table 12

## SUMMARY OF TEST RESULTS

Date of Test	Series No.	Specimen Weight, grams	Green Compressive Strength, psi.		Description of Foundation
			Permeability	Green Strength,	
11/17/43	1	152	128	6.623	Board as described
	2	152.5	126	6.495	Board with 29.5 lb.
	3	153.5	121.6	6.704	60.5 lb.
	4	154	123.2	6.753	95.6 lb.
	5	154	122.8	6.968	130.9 lb.
	6	154.5	119	7.052	166.0 lb.
	7	155	112.3	7.244	Concrete floor plus 65 lb., no corks
	8	154.5	119	6.962	Shock absorbers plus 166 lb.
	9	153.5	128	6.866	35.1 lb.
	10	155.5	115	7.236	Iron stand
	11	155	115	7.294	Corner of table
11/19/43	12	155	118	7.472	Concrete floor—corks
	13	154	123.2	7.138	Shock absorbers plus 261.7 lb.
	14	154.5	122	7.471	Wooden post
	15	154	125.6	7.368	Iron stand
	16	154	126.2	7.489	Iron stand
	17	153	128	7.210	Board with 328 lb.
	18	154.5	126	7.526	Corner of table

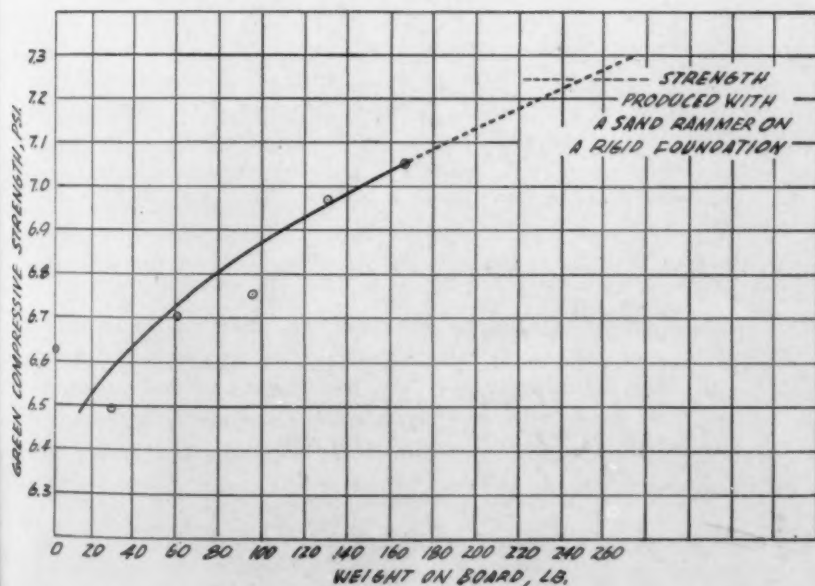


FIG. 33—STRENGTH AS A FUNCTION OF WEIGHT OF REACTION BLOCK.

Table 13

## COMPARISON OF RESULTS ON DIFFERENT DAYS USING RIGID FOUNDATIONS

<i>Date</i>	<i>Series No.</i>	<i>Average of Series, psi.</i>	<i>Deviation from the average</i>	<i>Per Cent Deviation from the average</i>
11/17/43	7	7.244	0.014	0.19
	10	7.236	0.022	0.30
	11	7.294	0.036	0.49
	7.258—Average compressive strength on rigid foundations			
11/19/43	12	7.472	0.007	0.09
	14	7.471	0.006	0.08
	15	7.368	0.097	1.30
	16	7.489	0.024	0.32
	18	7.526	0.061	0.82
7.465—Average compressive strength on rigid foundations.				

a difference in density, permeability and strength exists. This difference is most easily detected in the green compressive strength tests. Values for the conditions tested ranged from 6.50 to 7.53 psi.

2. Non-rigid supports should not be used. These include wooden tables, tables on wooden floors, etc. Setting the rammer over the leg of a heavy table seems to be very satisfactory if supported on a concrete floor or foundation.

3. Shock absorbing devices, even with large weights between the rammer and the shock absorbers, do not produce specimens equivalent to those made on rigid supports.

4. Only minor differences were found to exist between the various types of rigid support. Steel, concrete or wooden columns, securely anchored, with the rammer fastened tightly to the top, are all satisfactory. They should rest on a substantial floor, preferably of concrete. Mounting the rammer directly over the leg of a heavy table produced good results. In this case, care should be taken to be sure that the fit between the rammer base and the table top is good.

5. All four legs and the boss under the drop weight should bear on the support and the rammer should be securely bolted down.

6. It is desirable to have the bottom side of the rammer base machined flat or at least so that the boss and all the legs are in the same plane. A good fit to any flat surface is then assured.

## ACKNOWLEDGMENT

The Sub-Subcommittee owes thanks to R. E. Morey, Naval Research Laboratory, who conducted the tests and prepared the report; also to the Navy Department for sponsoring the work.

# Development and Properties of Sand Cast Aluminum Alloy Having High Strength After Ageing Without Previous Heat-Treatment

BY HIRAM BROWN\*, NIAGARA FALLS, N. Y.

## Abstract

*The author has described the development and properties of a sand-cast aluminum-base alloy containing magnesium, zinc, and small amounts of titanium and chromium. This alloy has the ability to develop high strength properties on ageing without undergoing previous heat treatment. Throughout the article the author refers to the alloy as alloy B-81.*

## INTRODUCTION

1. High strength aluminum-zinc-magnesium alloys have been known and used in Europe for a long time, particularly in Germany. However, it has been only within the past few years that an alloy of this type has been accepted for wide commercial usage in the United States, although some aluminum-zinc alloys have been used for special purposes for quite a few years.

2. Alloys of the aluminum-copper type have been most prominent in this country chiefly due to the fact that copper was plentiful and strengthens aluminum effectively even in small amounts. Other contributing factors are that these alloys are easy to work with in the foundry, and a wide range of physical properties could be obtained by varying the copper content, even before the effect of heat-treatment was discovered. With heat-treatment even higher strengths, with fair ductility, were found to be possible.

## DEVELOPMENT OF ALUMINUM-MAGNESIUM-ZINC ALLOYS

3. It was Alfred Wilm who, over thirty years ago in Germany, first discovered that an aluminum-copper alloy of the Duralumin type could be aged (precipitation hardened). He found that an alloy consisting principally of aluminum with copper and a small amount of magnesium possessed the peculiar property of hardening slowly after it had been subjected to an appropriate high temperature heat-treatment, with an accompanying increase in

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physical properties. This discovery was the beginning of the aluminum heat-treating industry, although it was much later that any theories were advanced as to the probable cause of the phenomena. Although this momentous discovery was made in Germany, the use of aluminum-copper alloys was more widely accepted in America than it was in European countries. This was due to the fact that European nations did not have access to copper resources as large as ours and it was necessary for them to import most of their copper. The result was that those nations were forced to turn to other alloying elements such as zinc, magnesium, and silicon, which could be more readily obtained. It was soon found that aluminum-zinc-magnesium alloys were capable of attaining very high strength and could also be heat-treated and aged (precipitation hardened) to even higher strength.

4. Despite the progress made with aluminum-zinc-magnesium alloys, they were not widely used in the United States because several disadvantages became associated with these alloys. It was found that aluminum alloys with high zinc and magnesium were difficult to fabricate, and had low corrosion resistance and a decided susceptibility to stress corrosion cracking. Fabricating difficulties have been overcome by lowering the magnesium and zinc content, and it was proved that elements other than zinc and magnesium caused the corrosion and stress corrosion cracking difficulties. This is covered in detail further along in this paper. However, by the time these defects were corrected, the aluminum-copper and aluminum-silicon alloys had gained widespread usage, and aluminum-zinc-magnesium alloys had to fight their way through the barriers of out-moded prejudices and the popular acceptance of other aluminum alloys which made consumers reluctant to accept new alloys in the place of old stand-bys.

5. The aluminum-zinc-magnesium alloys have been able to overcome the obstacles and prove their worth, but until recently progress has been slow. Guertler and Sander<sup>1</sup> made a valuable contribution when they found that excellent results were obtained when zinc and magnesium were present in the amounts necessary to combine completely to form the compound  $MgZn_2$ . This compound is believed to be principally responsible for the ageing of such alloys. Guertler and Sander found that improvement in tensile strength for aluminum- $MgZn_2$  types of alloys commenced with about 4 per cent by weight of  $MgZn_2$ . It was also noted that too large a percentage of  $MgZn_2$  decreased the workability of the alloys. Improvement in tensile properties was obtained by quenching followed by either natural or artificial ageing.

6. Fuller and Basch\* made still further advancement when they found that best properties were obtained by limiting the zinc to 4-6 per cent and the magnesium to 0.5-1.25 per cent. They found that aluminum alloys within those ranges flowed freely in molds, produced castings having sharp outlines, and could be worked readily by machine tools. Thus the zinc and magnesium

<sup>1</sup> Superior numbers refer to references at the end of this paper.

\*General Electric Co.



limits were defined at low percentages. This indicated that the rigid ratio of zinc and magnesium necessary to completely form  $MgZn_2$  did not give the optimum results, and that other ratios of magnesium and zinc gave better properties.

7. Comstock<sup>3\*</sup> further improved the alloys when he found that excellent tensile properties could be obtained from alloys containing zinc and magnesium within essentially the same range as Fuller and Basch, but not necessarily in the ratio of  $MgZn_2$ . Best results were obtained with magnesium-zinc ratios which did not hold to the  $MgZn_2$  formula, since it was found that other constituents were effective in strengthening the alloys. The series of alloys was further improved when Comstock found that chromium and titanium were beneficial for grain refinement, corrosion resistance, and increased strength. High strengths were obtained without the use of any heat-treatment.

8. It was subsequently found that best all around properties were obtained with an alloy<sup>\*\*</sup> having the following composition:

Zinc .....	5.25 per cent
Magnesium .....	0.50 per cent
Chromium .....	0.50 per cent
Iron, max. ....	1.00 per cent max.
Titanium .....	0.2 per cent
Copper, max. ....	0.4 per cent
Silicon, max. ....	0.3 per cent
Aluminum .....	Remainder

This alloy was found to have good casting properties and to be without many of the disadvantages earlier associated with aluminum-zinc alloys. The lower zinc and magnesium contents made the alloy easier to fabricate.

#### AGEING

9. The outstanding property of this alloy, however, is its ability to attain high strength by natural ageing. Many alloys will age after solution or quenching heat-treatment. Aluminum-zinc-magnesium alloys were found to age rapidly at room temperature or to respond readily to artificial ageing after a solution heat-treatment to give very high physical properties. Alloy B-81 has been found, however, to attain high physical properties by natural ageing or artificial ageing without a previous solution or quench heat-treatment†.

10. Physical properties obtained with ageing are equivalent or superior to most of the cast high-strength, heat-treated alloys.

\*Titanium Alloy Mfg. Co.

\*\*RECOMMENDED PRACTICES FOR THE SAND CASTING OF NON-FERROUS ALLOYS, published by the American Foundrymen's Association, 1944. Page 125 (Alloy B-81).

†This ageing consists of 10 hr. at 356° F.  $\pm$  10° F., and was perfected by General Electric Co.

11. The following properties of the alloy B-81 have been specified in Army-Navy Air Corps Specifications AN-A-17:

Yield Strength, min., 20,000 psi.  
Tensile Strength, min., 32,000 psi.  
Elongation, min., 3.0 per cent in 2 in.

Other specifications covering the same alloy are U. S. Navy Bureau of Ships Specification 46A1(INT), Class 1, and A.S.T.M. Specification B26-41T, Alloy ZG41.

12. The term "ageing" is used in this paper to mean general improvement of various mechanical properties in the course of time. Natural ageing means that the process is carried out at normal room temperature, while artificial ageing means that a temperature higher than room temperature is used.

13. After alloy B-81 is cast and allowed to stand at room temperature, a change in physical properties takes place, rapidly at first, then more slowly later in the process. Yield and tensile strengths are raised considerably and elongation is progressively decreased. The properties of the alloy reach the above specifications within three weeks at room temperature and increase very little thereafter. If it is undesirable to wait for the natural ageing cycle, the alloy can be artificially aged in a matter of hours to meet the required specifications.

14. The ability of this alloy to age to high physical properties is the answer to many jobs that heretofore have caused numerous headaches as a result of the warpage, distortion, and cracking resulting from quenching from high temperatures, and other difficulties commonly associated with heat-treating. It also has made possible the casting of large pieces which would otherwise necessitate large, expensive heat-treating equipment, and has thus made possible the casting of high strength aluminum in foundries which do not have the facilities for heat-treating aluminum alloys. Many foundries which never before made high strength aluminum alloys have found alloy B-81 a welcome addition to their alloy list. This is particularly true of smaller foundries, as well as large ones.

#### *Mechanism of Ageing*

15. The phenomena of ageing are dealt with at length in other papers on this alloy.<sup>4,5</sup> However, in order to facilitate the interpretation of the data and comments of this paper, it seems worthwhile to repeat some of the information at this time. Just what ageing is and how it takes place have been widely debated for years without a decision. However, each investigator contributes some valuable information which helps to clarify the issue a little. As a matter of fact, it has been only recently that any workable theories have been evolved.

16. Ageing can occur in an alloy when some constituent is more soluble at a higher than at a lower temperature. When an alloy is cast and subse-

quently allowed to cool, the rate of cooling, even though it is relatively slow, is not slow enough to maintain equilibrium conditions. In the solid metal grains are trapped constituents in solution which would have precipitated as the temperature decreased had cooling been sufficiently slow. The result is that the metal is not stable since there is a natural tendency, slow at ordinary room temperature and more rapid if the temperature is raised slightly, for the excess constituents to precipitate so that stability can be achieved. This precipitate is so finely divided that it usually is not seen under the microscope and so has been described as sub-microscopic. Recently several investigators have reported that by extremely careful polishing and etching they have been able to see this precipitate in the early stages of ageing.<sup>6</sup> Others have not confirmed these findings. The usual experience is that when the particles become visible under the microscope the ageing has passed its most effective limit.<sup>7</sup>

17. It is known that the size and extent of distribution of the precipitate have a pronounced effect on the mechanical properties. There seems to be a "critical" precipitate particle-size that exerts a maximum influence on the properties. When this size is exceeded, the effect of the precipitate is much less. Best tensile properties usually result from the most highly dispersed condition of the precipitate with the finest possible state of division. In alloy B-81 this occurs with natural ageing. This is verified by the fact that while yield strength increases with artificial ageing treatment of 10 hours at 356° F. (180° C.), the tensile strength and elongation are lower than the same properties obtained by natural ageing. Several examples of this are given in Table 1.

Table 1

COMPARISON OF TENSILE PROPERTIES RESULTING FROM NATURAL AND ARTIFICIAL AGEING OF ALLOY B-81

Heat No.	Treatment	Yield-Strength, psi.	Tensile-Strength, psi.	Elongation, Per Cent in 2 in.
C173-6	10 hrs., 356° F. (180° C.)	26,200	34,000	5.5
C173-6	21 days, room temp.	23,150	38,200	9.25
C149	10 hrs., 356° F. (180° C.)	25,350	33,800	4.5
C149	21 days, room temp.	24,000	37,450	8.0
C164	10 hrs., 356° F. (180° C.)	27,500	34,700	5.0
C164	21 days, room temp.	24,200	37,000	8.0

#### Overageing

18. This decrease in tensile strength with increase in temperature is believed to be due to the fact that with higher temperature the critical size of the precipitate is exceeded and maximum effect is not achieved. Overageing is the term usually applied to such action, and the degree of overageing depends upon the temperature. Artificial ageing accelerates precipitation because the higher temperature increases the mobility of the atoms and thus increases the rate at which the precipitate can form. It is possible that when the mobility

Table 2

EFFECT OF TIME AT 356° F. (180° C.) ON TENSILE PROPERTIES OF ALLOY B-81

<i>Hours at Temp.</i>	<i>Yield- Strength, psi.</i>	<i>Tensile- Strength, psi.</i>	<i>Elongation, Per Cent in 2 in.</i>
6	23,950	32,150	5.0
10	23,700	33,000	5.75
14	25,300	32,000	6.0
18	23,700	32,000	6.5
24	25,000	32,650	6.0

of the atom is too great, several precipitate particles may join to form a single large particle, thus reducing the effect of the critical size, and resulting in weakening or overageing.

### Artificial Ageing

19. The question then arises why artificial ageing should be used at all. In many cases it is neither desirable nor possible to wait three weeks for natural ageing to take place. Artificial ageing cuts the time to a matter of hours instead of days, casting strains are relieved, and the metal is stabilized so that close-tolerance machining can be done without growth or warpage occurring. Castings of all sizes, shapes, and thicknesses have been machined to close tolerances after artificial ageing.

20. The artificial ageing of alloy B-81 is much more sensitive to temperature than it is to time. For example, test bars were held at 356° F. (180° C.) for periods of from 6 to 24 hours. After 6 hours there was very little change in tensile properties even after holding at temperature for 24 hours, as shown in Table 2.

Table 3

EFFECT OF HOLDING BARS OF ALLOY B-81 AT ROOM TEMPERATURE FOR 21 DAYS AFTER AGEING AT 356° F. (180° C.)

<i>Treatment</i>	<i>Yield- Strength, psi.</i>	<i>Tensile- Strength, psi.</i>	<i>Elongation, Per Cent in 2 in.</i>
6 hrs., 356° F. (180° C.)	23,950	32,150	5.0
6 hrs., 356° F. + 21 days, room temp.	23,350	32,600	5.25
10 hrs., 356° F. (180° C.)	23,700	33,000	5.75
10 hrs., 356° F. + 21 days, room temp.	24,450	32,450	5.25
14 hrs., 356° F. (180° C.)	25,300	32,000	6.0
14 hrs., 356° F. + 21 days, room temp.	24,250	32,700	6.5
18 hrs., 356° F. (180° C.)	23,700	32,000	6.5
18 hrs., 356° F. + 21 days, room temp.	24,000	32,000	5.5
24 hrs., 356° F. (180° C.)	25,000	32,650	6.0
24 hrs., 356° F. + 21 days, room temp.	24,950	32,000	6.25

Table 4

EFFECT OF TIME AT 400° F. (204° C.) ON TENSILE PROPERTIES OF ALLOY B-81

Hours at Temp.	Yield- Strength, psi.	Tensile- Strength, psi.	Elongation, Per Cent in 2 in.
1	18,350	29,900	11.75
2	19,450	29,700	9.0
4	20,200	28,000	8.25
6	18,675	27,700	10.0
10	18,100	26,650	10.5
14	18,950	27,200	9.5
10 hrs., 356° F. (180° C.)	25,200	33,600	7.0

21. To find whether the properties obtained in Table 2 were stable, bars from the same heat, and aged with those represented in Table 2, were held for 21 days at room temperature and then tested. The comparison of these bars with those pulled immediately after ageing (Table 2) is shown in Table 3. No notable increases or decreases in properties were found, indicating that the metal properties were well stabilized after the ageing treatment of 10 hours at 356° F. (180° C.).

22. It should be noted at this point that none of the test bars used in any of the tests presented in this paper were cast under research or laboratory conditions. All bars were taken from regular production runs in the foundry. For that reason, the properties shown are not always far above specifications. The primary purpose of these tests was to find procedures which will apply to regular production rather than to selected heats made under ideal conditions.

23. On the other hand, when the temperature was raised to 400° F. (204° C.), overageing and consequent poor properties were obtained after as little as two hours, as shown in Table 4.

24. It has been shown in a previous paper<sup>8</sup> that tensile properties of bars aged at 400° F. (204° C.) and above are not stable, but show considerable change in properties when allowed to stand at room temperature after ageing.

25. There is also a definite effect due to the holding time room temperature before artificial ageing. Table 5 shows that bars held at room tempera-

Table 5

EFFECT OF TIME AT ROOM TEMPERATURE BEFORE 10 HOURS AT 356° F. AGEING ON TENSILE PROPERTIES OF ALLOY B-81

Time at Room Temp. Before Artificial Ageing	Yield- Strength, psi.	Tensile- Strength, psi.	Elongation, Per Cent in 2 in.
24 hours	23,800	32,450	7.0
48 hours	25,200	33,450	4.75
72 hours	25,350	33,800	4.5
7 days	25,650	35,550	5.5

Table 6

COMPARISON OF TENSILE PROPERTIES OF BARS OF ALLOY B-81 AFTER  
QUENCHING WITH THOSE ARTIFICIALLY AGED

<i>Treatment</i>	<i>Yield- Strength, psi.</i>	<i>Tensile- Strength, psi.</i>	<i>Elongation, Per Cent in 2 in.</i>
2 hrs., 1090° F. (588° C.), water quench	15,900	30,750	9.75
2 hrs., 1090° F. (588° C.), water quench + 21 days room temp.	27,550	34,700	4.25
10 hrs., 356° F. (180° C.)	27,300	34,500	4.5

ture for 48 hours before artificial ageing have higher yield and tensile strengths and lower elongation than those held only 24 hours before artificial ageing. Bars held 72 hours before artificial ageing do not show enough increased strength to justify the extra 24-hours holding. Bars held seven days gave better properties than those held 24, 48, or 72 hours, but again the time element makes this holding period impractical.

26. Table 6 shows the comparison between artificially aged bars and bars quenched from high temperature and naturally aged for 21 days.

#### *Reageing*

27. Previous investigations<sup>5</sup> have shown that the alloy B-81 also possesses the ability to reage when cooled to room temperature after exposure to high temperature. Table 7 shows that test pieces held for 2 hours at temperatures as high as 1050° F. (565° C.) and allowed to air cool, naturally reaged to attain high physical properties equivalent to those of the same material which had not been exposed to high temperatures.

Table 7

REAGEING OF ALLOY B-81 AFTER EXPOSURE TO HIGH TEMPERATURES

<i>Treatment</i>	<i>Yield- Strength, psi.</i>	<i>Tensile- Strength, psi.</i>	<i>Elongation, Per Cent in 2 in.</i>
21 days, room temp., no exposure to high temp.	25,000	36,700	6.5
2 hrs., 900° F. (482° C.), air cool, aged 21 days room temp.	25,100	35,600	5.5
2 hrs., 1000° F. (538° C.), air cool, aged 21 days room temp.	25,400	36,800	6.0
2 hrs., 1050° F. (565° C.), air cool, aged 21 days room temp.	24,800	38,300	6.0
2 hrs., 1000° F. (538° C.), air cool, reheat 2 hrs., 1000° F. (538° C.), air cool, aged 21 days room temp.	25,550	36,000	5.25



## WELDING

28. The results indicate that there should be a wide field of use of this alloy for parts which are to be brazed or welded. This is especially true where the brazed assembly may be intricate or bulky and thus difficult to heat-treat in its entirety.

29. Preliminary tests demonstrated that welding does not materially affect the strength of the metal, and even in the welds, properties compared favorably with those of the parent casting. Tests are now in progress to investigate more thoroughly the strengths of welded material made from this alloy.

## CORROSION RESISTANCE

30. In addition to the natural ageing and reageing properties of the alloy, many of the disadvantages previously associated with aluminum-zinc alloys have been overcome. Ample evidence has demonstrated that alloy B-81 has high corrosion resistance, comparable to that of some silicon and silicon-magnesium alloys.<sup>4</sup> It has been proved that aluminum-base alloys with zinc as high as 9 per cent showed practically no deterioration after immersion in sea water for 448 days. Serious corrosion in sea water and in tap water was found when the alloys contained both zinc and copper.<sup>8</sup> This is evidence that zinc alone does not impair the corrosion resistance. Aluminum alloys containing zinc and magnesium have been found to have good resistance to corrosion, as long as copper is absent. Most aluminum-zinc alloys used in the past contained copper as an alloying element, which was responsible for their poor resistance to corrosion. Alloy B-81 contains magnesium but not copper. The presence of titanium and chromium further improves the natural corrosion resistance of the alloy.

*Corrosion Fatigue*

31. It was pointed out earlier in the paper that aluminum-zinc and aluminum-zinc-magnesium alloys fell early in disfavor because they were subject to stress corrosion cracking. Under stress corrosion (or corrosion fatigue) it is the corrosion resistance and not the normal mechanical properties of the metal which determines the life of any part under such conditions.<sup>9</sup> Since alloy B-81 was known to be resistant to corrosion, a simple test was made to see whether it would resist corrosion under stress. Test pieces like that shown in Fig. 1 were made.

32. One test piece was cast of 4 per cent copper alloy and heat-treated. Another was cast of 7 per cent silicon, 0.3 per cent magnesium alloy. A third piece was cast of the B-81 alloy. The test bars were placed on a board and bent at each end by tightening bolts so that the ends almost touched the board, as shown in Fig. 2. This was intended to stress the center of the test piece.

33. After the test pieces were stressed in the foregoing manner, the board

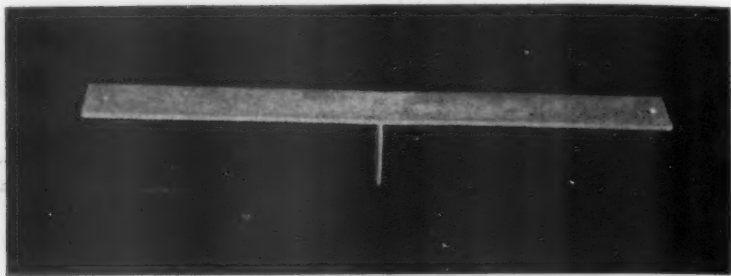


FIG. 1—TEST PIECE USED TO COMPARE RESISTANCE TO CORROSION FATIGUE.

was then turned upside-down and allowed to float in a 5 per cent sodium chloride solution so that the test pieces were suspended in the solution. The board was allowed to remain in the solution all day and was removed each night. After seven days the 4 per cent copper alloy broke across the center at the stressed area and the material was considerably pitted and corroded. This broken piece is shown in Fig. 3, top. Neither of the other pieces evidenced any bad corrosion effects.

34. It was thought that possibly the first 4 per cent copper alloy test piece had been defective, so a second one was cast and mounted on the board as before. After 9 days this piece also broke across the center at the stressed area and was considerably pitted and corroded. This broken piece is shown in Fig. 3, bottom.

35. Alloy B-81 and the 7 per cent silicon, 0.3 per cent magnesium alloy test pieces have been subjected to the test continually for five months. The silicon-magnesium alloy seems to show more etching or pitting than does alloy B-81, but neither shows any sign of cracking. Figure 4 shows these two pieces after 16 weeks in the salt bath.

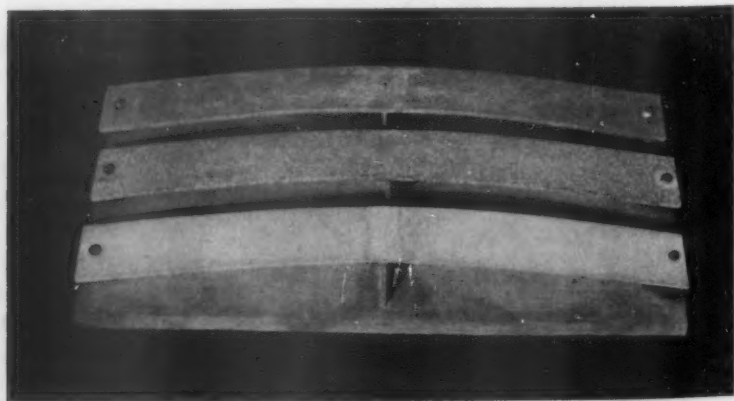


FIG. 2—METHOD OF STRESSING CORROSION-FATIGUE SPECIMENS.

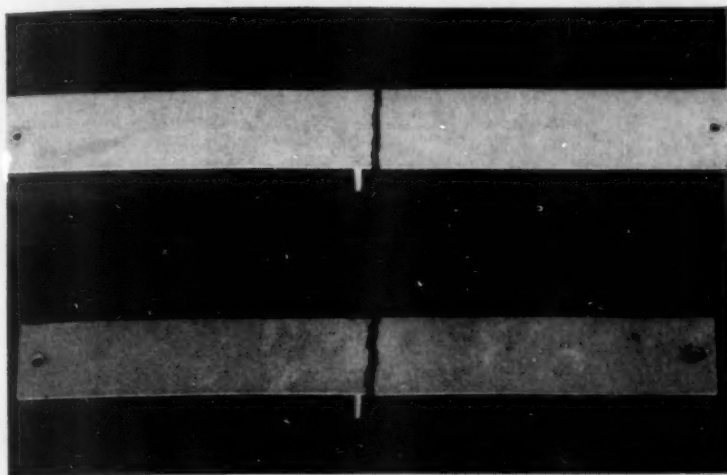


FIG. 3—TEST PIECES OF 4 PER CENT COPPER ALLOY.  
TOP—FAILURE OCCURRED AFTER SEVEN DAYS. BOTTOM—FAILURE OCCURRED AFTER NINE DAYS.

#### CASTING PROPERTIES

36. Alloy B-81 can be cast in thin sections or intricate shapes. It has higher shrinkage than the aluminum-copper alloys and requires adequate gating and risering to compensate for this. The alloy can be poured over a wide pouring range.

#### POURING TEMPERATURES

37. Satisfactory physical properties can be obtained in test bars poured between  $1250^{\circ}\text{ F.}$  ( $677^{\circ}\text{ C.}$ ) and  $1475^{\circ}\text{ F.}$  ( $802^{\circ}\text{ C.}$ ), but maximum test bar properties are obtained between  $1325^{\circ}\text{ F.}$  ( $718^{\circ}\text{ C.}$ ) and  $1375^{\circ}\text{ F.}$  ( $746^{\circ}\text{ C.}$ ),

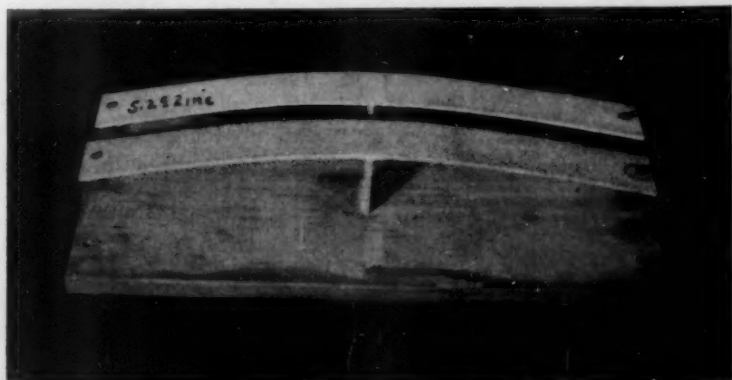


FIG. 4—TEST PIECES OF B-81 AND 0.3 PER-CENT MAGNESIUM, 7 PER CENT SILICON ALLOYS AFTER IMMERSION IN A SALT BATH FOR SIXTEEN WEEKS.

Table 8

EFFECT OF POURING TEMPERATURE ON ARTIFICIALLY AGED TEST BARS OF  
ALLOY B-81

Pouring Temperature		Yield- Strength,	Tensile- Strength,	Elongation, Per Cent
$^{\circ}$ F.	$^{\circ}$ C.	psi.	psi.	in 2 in.
1475	802	24,000	32,000	4.75
1425	774	24,000	32,300	4.75
1400	760	25,900	34,750	6.75
1375	746	25,050	33,700	6.25
1350	732	26,200	34,000	5.5
1325	718	26,100	35,100	6.5
1300	704	25,250	34,400	5.5
1250	677	25,150	34,600	5.25

as shown in Table 8. The data in Table 8 show that while yield strength, tensile strength, and elongation were within specifications at all pouring temperatures between 1250° F. (677° C.) and 1475° F. (802° C.), all of these properties increased noticeably when temperatures of 1400° F. (760° C.) or less were used.

38. The metal used in this series of tests was heated to slightly above 1475° F. (802° C.) and test bars were poured at intervals as the metal cooled. This was done to simulate actual melting conditions in the foundry.

39. Because of the tendency for an alloy of this type to form dross and the relative sluggishness of the alloy when cold, it is advisable to pour it above 1300° F. (704° C.) to avoid the retention of dross and oxide in the metal. The higher pouring temperature of the alloy is more than offset by the fact that this metal does not have the pinhole porosity which is common to aluminum-copper alloys, and its tendency to pick up gas during melting is much less.

## TEST BAR MOLDS

40. Foundry characteristics of alloy B-81 are comparable to those of the 4 per cent copper alloy, but not as good as those of the 7 per cent silicon, 0.3 per cent magnesium alloy. Unlike most aluminum alloys, B-81 test bars develop maximum properties when large open risers are used at each end of the mold, and no chokes or strainers are used. The metal is poured through a center

Table 9

COMPARISON OF TEST BAR CUT FROM CASTING WITH SEPARATELY CAST TEST  
BARS OF 5.25 PER CENT ZINC ALLOY FROM SAME HEAT

Test Bars	Tensile- Strength, psi.	Elongation, Per Cent in 2 in.
Separately cast	36,100	5.25
Machined from casting	34,100	6.0

Table 10

TENSILE TESTS OF TEST BARS CUT FROM ALLOY B-81 PISTON WHICH HAD BEEN IN SERVICE FOR SIX MONTHS

<i>Bar</i>	<i>Yield- Strength, psi.</i>	<i>Tensile- Strength, psi.</i>	<i>Elongation, Per Cent in 2 in.</i>
1	28,250	35,000	4.0
2	28,500	35,500	3.0
3	26,750	37,250	5.5
4	30,750	35,750	3.0
5	30,000	33,750	3.0

sprue and allowed to flow into the test bar section from both ends. Cleaner metal is obtained this way than when chokes or strainers are inserted in the mold, or when the metal is allowed to enter the test bar section from one end only. This may seem paradoxical but many experiences and tests have confirmed this.

#### MELTING LOSSES

41. The metal can be melted repeatedly without serious deterioration, provided its composition is maintained substantially constant. Small additions of magnesium and zinc should be the only adjustments required. Overheating the metal will do its greatest damage by burning out magnesium and, if this happens, care must be taken to compensate for such loss.

#### STRENGTH OF TEST BARS CUT FROM CASTINGS

42. Castings made from this alloy have a very high percentage of the strength obtained in separately cast test bars. This is true of both light and heavy sections. A small casting from the regular production run of a customer's pattern was taken and a test bar machined from a portion of it. This was checked against separately cast test bars of the same heat. Table 9 shows that the results compared very favorably. Both casting and test bars had been artificially aged.

43. Five large pistons which had been in service for six months were sectioned and test bars taken from the heavy section of each casting. Table 10 shows that all of the bars had good tensile properties.

#### APPLICATIONS

44. Alloy B-81 is being used in a wide variety of commercial applications. Some of the parts must withstand 300 pounds hydrostatic pressure. Ventilating fans for firing chambers of ships have been made of this alloy for some time. Aircraft uses include oxygen control units for high altitude flying, self-sealing gasoline tanks, undercarriage parts, radio and Radar equipment, oil line inlets, and the top turret of the Flying Fortress.

45. Machinability of alloy B-81 is excellent, far superior to either 4 per cent copper alloy or 7 per cent silicon, 0.3 per cent magnesium alloy, and probably even better than the standard 8 per cent copper alloy. The machined metal has a high lustre.

46. Coatings produced by the chrome and anodic treatment are entirely satisfactory.

#### SUMMARY

46. Investigation of the properties of B-81 has demonstrated the following:

- (1) Aluminum alloys containing zinc and magnesium attain high strength by ageing without prior heat-treatment.
- (2) Zinc-Magnesium ratios other than that required to produce  $MgZn_2$  were found desirable.
- (3) Addition of titanium and chromium improved properties still more.
- (4) Heat-treatment problems are eliminated because no high temperature or quench treatments are necessary.
- (5) Either artificial or natural ageing can be used. Artificial ageing saves a great deal of time and stabilizes the metal so that close tolerance machining can be done.
- (6) Effect of ageing temperature is much more critical than time at temperature.
- (7) Time at room temperature before artificial ageing has a pronounced effect on physical properties.
- (8) Alloy B-81 will reage to attain high strength when cooled to room temperature after being held at high temperature.
- (9) The alloy is easily fabricated, has high corrosion and stress corrosion resistance, shock resistance, and can be readily machined and anodized.
- (10) The alloy is less sensitive to high temperatures and porosity than the standard aluminum-copper alloys.
- (11) A high ratio of casting to test bar properties is obtained.
- (12) Foundry characteristics are comparable to those of the 4 per cent copper alloy but not as good as those of the 7 per cent silicon, 0.3 per cent magnesium alloy.

#### ACKNOWLEDGMENT

47. The author wishes to acknowledge the large amount of work done on this alloy by General Electric Co., especially in the early development. The work is now being continued by the author's company with the continued assistance of General Electric Co.



## Bibliography

1. Guertler and Sander, U. S. Patent No. 1,629,699, May 24, 1927.
2. Fuller and Basch, U. S. Patent No. 1,578,979, March 30, 1926.
3. Comstock, G. F., U. S. Patent No. 2,146,330, February 7, 1939.
4. Brown, Hiram, "High Strength Natural Aging Aluminum Alloy," *AERO DIGEST*, May, 1943.
5. Brown, Hiram, "High Strength Casting Alloy with Natural Reaging Properties." Paper presented at 12th annual meeting of Institute of Aeronautical Sciences, Columbia University, January 25, 1944.
6. Fink, W. L., Smith, D. W., and Willey, L. A., "Precipitation Hardening of High Purity Binary and Ternary Aluminum-Copper Alloys." Symposium on Precipitation Hardening during 21st annual convention of the American Society for Metals, Chicago, October 23-27, 1939.
7. Mehl, R. F., and Jetter, L. K., "The Mechanism of Precipitation from Solid Solution. *The Theory of Age Hardening*." Same symposium as above.
8. Rosenhain, Archbutt, and Hanson, "11th Report to Alloys Research Committee of the British Institute of Mechanical Engineering," 1921.
9. Gouch, "Autumn Lecture to Institute of Metals," p. 17, (1932).

## DISCUSSION

Presiding: DR. N. E. WOLDMAN, Eclipse-Pioneer Div., Bendix Aviation Corp., Teterboro, N. J.

Co-Chairman: W. E. MARTIN, Sperry Gyroscope Co., Flushing, N. Y.

CHAIRMAN WOLDMAN: How does the castability of this high zinc aluminum alloy compare with that of the aluminum 355 alloy?

MR. BROWN: It compares with the aluminum 195 alloy. The castability is not as good as that of the silicon alloys by any means. It tends to be a little sluggish at low temperatures. In order to secure the same satisfactory results, we recommend a pouring temperature 30° higher than that of the alloys ordinarily used.

CHAIRMAN WOLDMAN: Can you cast thin wall sections?

MR. BROWN: Yes, providing we get the metal hot.

CHAIRMAN WOLDMAN: Is there any trouble from overheating?

MR. BROWN: Not as long as the metal is kept under 1475° F. It does not tend to pick up gases the way the aluminum-copper alloy does. That is very beneficial where a high temperature is necessary to make the metal flow.

MEMBER: How about dimensional stability after ageing?

MR. BROWN: The alloy has been used in the manufacture of radar equipment, in Flying Fortress turrets, and for all kinds of small parts, and it has never been turned back because of warping after machining. It goes into oxygen units for high altitude flying. So we must assume we are not going to experience any trouble as far as dimensional stability is concerned.

CHAIRMAN WOLDMAN: Mr. Brown stated that the physical properties of the 40-E alloy decreased when it was heated to 400° F., and then, upon heating to 1000° F., the physical properties increased, probably due to a partial solution of the intermetallic compound. Were any tests made on accelerated ageing after the 1000° F. treatment, and was there a still further increase in properties?

MR. BROWN: I will say that we got decidedly important results when we did that. We feel that we can produce an aluminum alloy having a 30,000-lb. minimum yield strength with 3 per cent elongation.

MR. BROWN (*author's closure*): As a test of the dimensional stability during machining operations, a parabola of about 30-in. diameter and dished like a searchlight reflector was cast from this alloy. After ageing, it was set up for machining, but, before machining began, set screws were placed at different parts of the casting with definite clearances between the set screws and the casting so that any distortion of the casting could be measured by checking at these various points after machining. When the machining operations were finished, the entire dish of the parabola had been machined, which gives an indication of the amount of metal removed. The clearances were then checked at the various set screws. A 0.001-in. gage was used to check detectable movement, but nowhere could any such movement be found with this gage, which indicates definitely that any distortion or change in dimension during machining was less than 0.001 in.

We hope soon to be permitted to publish the full details of the test, but meanwhile it is hoped that the summary given herein will answer, somewhat, the questions in regard to dimensional stability of the alloy.

## Mold Atmosphere Control

By H. W. DIETERT\*, R. L. DOELMAN\* AND R. W. BENNETT\*, DETROIT, MICH.

### INTRODUCTION

1. When metal is worked at elevated temperatures, it is essential to have control of temperature, time and atmosphere.

2. In the casting of metals in a mold, very little has been done in the way of atmosphere control in the mold, with the exception of the magnesium casting industry.

3. In the heat treating industry, where metals are subjected to moderate temperatures as compared to foundry casting temperatures, much progress has been made in using furnaces that have atmosphere control. When metal parts are treated in such furnaces, the machined surfaces of the parts are not deteriorated in finish or appearance and sales appeal is maintained. In the foundry, in order to make the casting surfaces passable, much expensive dressing in the cleaning room, where labor turnover is great and equipment is short-lived, is required.

### *Object*

4. The object of this paper is to show that, by incorporating mold atmosphere control so that the gases in the mold are not oxidizing, much of the work now being done in the cleaning room possibly may be eliminated, with a saving in labor, equipment, and compressed air cost.

5. The authors will endeavor to show, by dilatometer tests, how severely certain types of atmosphere affect the surfaces of steel test pieces, and how other types of atmosphere protect the surfaces of steel test pieces.

6. It was found that "penetration" types of casting defects are influenced greatly by the type of atmosphere present at the face of the mold.

### PENETRATION DEFECTS

7. A great deal of effort has been put forth in the foundry to prevent penetration defects, where a portion of the molten metal apparently enters the mold or core surface, tightly binding a thin section of the core or mold to the casting.

8. Many thin layers of such penetration peel quite readily from the casting, while a comparatively thick layer may result in many man hours being

\*President, Asst. Foundry Consultant and Sand Technician, respectively, Harry W. Dietert Co.

NOTE: This paper was presented at a Foundry Sand Development Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

expended in removing the mixed layer of sand and metal adhering to the casting.

#### *"Metal Penetration"*

9. Some penetration defects undoubtedly are caused by the presence of large pores in the face of the mold into which the molten metal could easily enter. Such porous areas of the mold may be due to soft-rammed molds, or to failure to apply sufficient ramming to overcome the low flowability of the sand. This type of penetration may be called "metal penetration."

#### *"Oxide Penetration"*

10. Another type of penetration, which may be called "oxide penetration," occurs more or less independently of the mold porosity. Oxide penetration, consisting of a mixture of metal and oxides of the metal, may be much greater in magnitude than is the case in metal penetration. In this paper, the authors will endeavor to show the mechanics of the oxide type of penetration.

11. In Fig. 1 are shown several variations of the oxide type of penetration. The penetration defect, Fig. 1-A, is a penetration of gray iron through a layer of mold wash into the face of the mold. The mold wash fell off when the penetration defect was removed. The penetration material is composed of free iron,  $\text{FeO}$ ,  $\text{Fe}_2\text{O}_3$ , a trace of  $\text{Fe}_3\text{O}_4$ , an iron silicate, and carbon of a higher percentage than the carbon content of the casting.

12. Figure 1-B shows a portion of the sand core of a steel casting mold which has been completely penetrated by metal. The composition of this defect is almost identical to that of the defect described in Fig. 1-A.

13. In Fig. 1-C is shown a cross section of a casting where the layer of silica flour wash is absent.

14. The cross-sectional view of casting peel, Fig. 1-D, distinctly shows a white layer, which is the silica flour wash through which the metal penetrated. These four examples are shown to illustrate the point that this penetration defect may occur either with or without the use of a mold or core wash. The penetration defect may, in certain cases, be eliminated by the use of a core or mold wash.

#### ACKNOWLEDGMENT

15. During a visit to the authors' laboratory, Howard Taylor, of the Naval Research Laboratory, mentioned burying a steel pin specimen in the dilatometer sand specimens ( $1\frac{1}{8}$  in. x 2 in.) as a good method of studying casting defects. The authors give full credit to the Naval Research Laboratory for the invention of the "steel pin immersion in sand specimen" test method, and appreciate their permission to use this test method to study the effect of mold atmosphere on casting defects so as to speed up the presentation of data secured from this very important test.

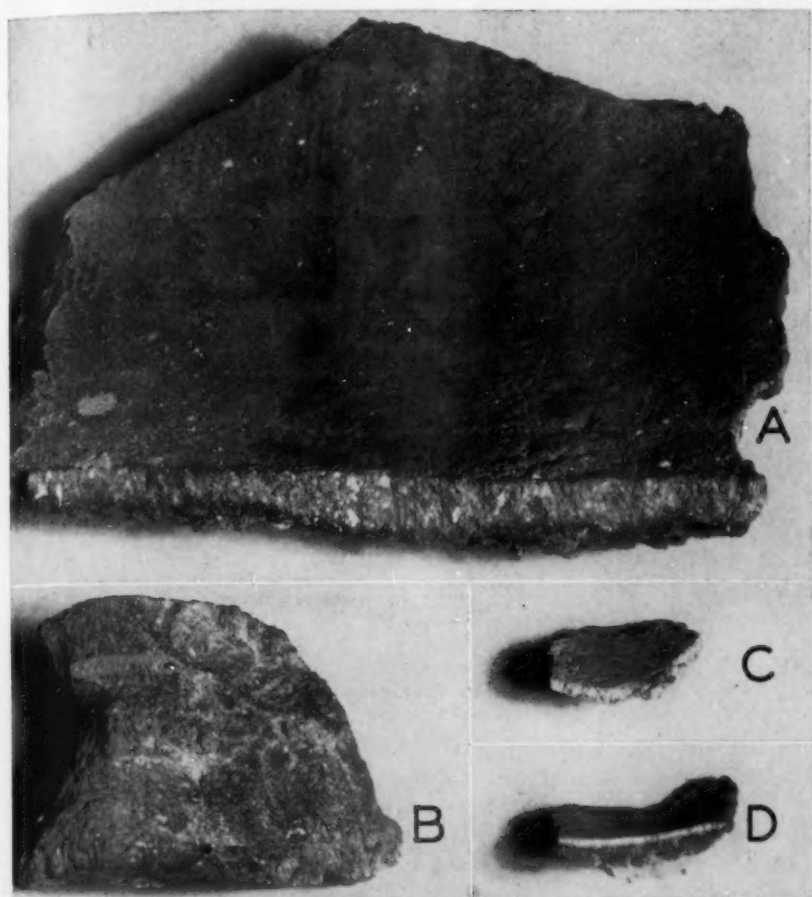


FIG. 1—OXIDE TYPE OF PENETRATION DEFECTS. A—PENETRATION OF GRAY IRON THROUGH A LAYER OF MOLD WASH INTO THE FACE OF THE MOLD. B—PORTION OF SAND CORE SHOWING COMPLETE PENETRATION BY METAL. C—PENETRATION DEFECT WHERE SILICA FLOUR WASH WAS NOT USED. D—VIEW OF CASTING PEEL. METAL PENETRATED THROUGH SILICA FLOUR WASH, WHICH IS SHOWN AS WHITE LAYER.

#### TEST METHOD

16. The  $1\frac{1}{8}$ -in. x 2-in. sand specimen, as used for elevated temperature sand testing, lends itself very well to determining the behavior of embedded metal specimens in molding materials at pouring temperatures when subjected to different gases.

17. Sand specimens were rammed with three drops of the weight of the special  $1\frac{1}{8}$  x 2-in sand rammer within the floating specimen tube arrangement, as illustrated in Fig. 2. This floating arrangement produces a double-end ramming effect, whereby both ends of the specimen are rammed to the same hardness. On top of the stripping post is placed a disc with a stem of  $\frac{1}{4}$ -in.

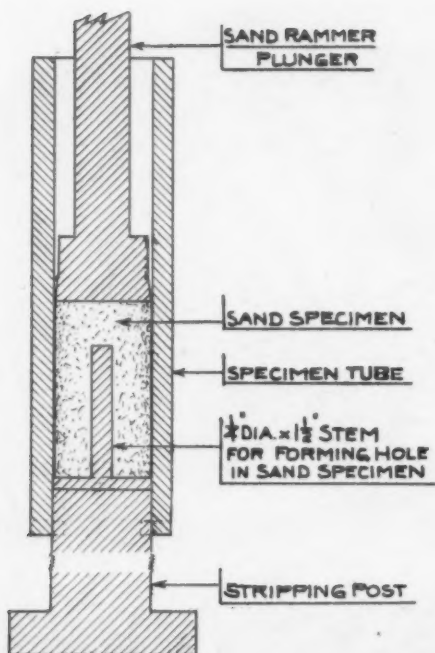


FIG. 2—VIEW OF SPECIMEN CONTAINER AND PATTERN USED FOR PENETRATION DEFECT TEST.

diameter and  $1\frac{1}{2}$ -in. length. This stem forms a hole in the sand specimens into which the  $\frac{1}{4}$ -in.  $\times$   $1\frac{1}{2}$ -in. metal specimen fits.

#### *Steel Test Pieces*

18. In all of the tests included in this paper, steel pins with a carbon content of 0.23 per cent were used. These steel pins, after cleaning with carbon tetrachloride, were pushed into the holes in the sand specimen, as shown in Fig. 3. Other pins with higher carbon content follow the same trend.

19. The sand specimen completely surrounds the test pin with the exception of the top end for the test method *A*, Fig. 3. In some cases, the top of the specimen was coped with a  $\frac{1}{2}$ -in. thick disc of sand.

20. For observation of metal penetration, the test method *B*, Fig. 3 was used and found exceedingly instructive.

21. Both green and dry sand specimens were used in this series of tests.

22. The sand specimens with the test pins were placed in the dilatometer furnace, Fig. 4, and were allowed to remain in the furnace for a period of 12 min. at temperatures ranging from  $1600^{\circ}$  F. to  $2900^{\circ}$  F.

23. The interior of the furnace was charged with many different gases. In other cases, various chemicals and facing materials were added to the sand used to form the sand specimens.



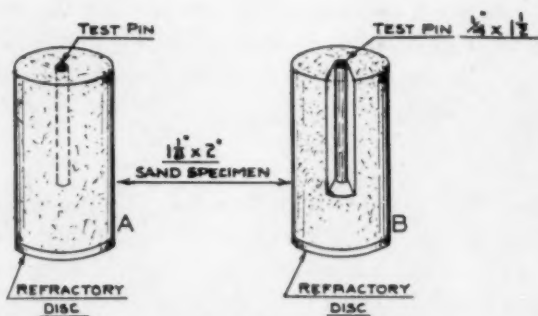


FIG. 3—VIEW OF SAND SPECIMENS WITH METAL PINS FOR PENETRATION DEFECT TEST. A—TEST PIN IMMERSED IN SAND SPECIMEN. B—SECTION OF SAND SPECIMEN CUT OUT FOR OBSERVATION OF TEST PIN.

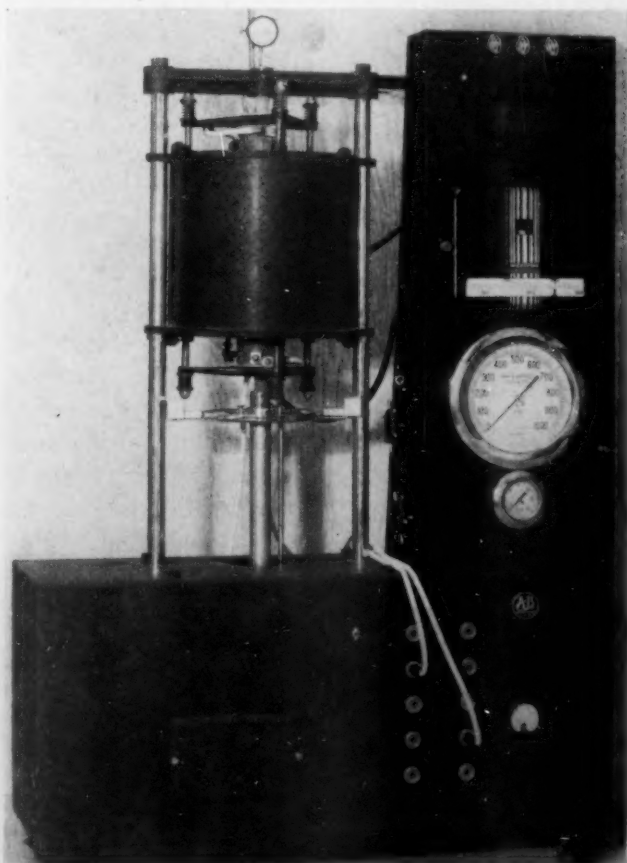


FIG. 4—DILATOMETER USED FOR HEATING PENETRATION TEST SPECIMENS.

24. The surface finish obtained on the test pin and the amount of penetration into the sand specimen were observed visually and recorded by photographic means. The amount of penetration also may be determined by weighing the penetrated material.

#### *Sand Mixtures*

25. The sand used in the tests reported in this paper consisted of the mixture shown in Table 1, with the exception of the sand used for the test as illustrated in Fig. 5, which contained 10 per cent of silica flour in addition to the ingredients shown in Table 1.

26. The sand was mixed in a muller and aerated and stored in air-tight containers for each day's supply of sand.

27. For the tests requiring dry sand specimens, the sand specimens were dried at 230° F. for a period of 3 hr.

#### *Temperatures*

28. The important part that temperature of the metal and of the mold surface plays in penetration is well illustrated in Fig. 5. This illustration shows the top views of sand specimens with test pins, also views of halved sand specimens showing penetration by the darkened areas surrounding the hole into which the test pin was inserted. The test pins are also shown so that the surface conditions may be studied. The test pins were completely absorbed for the 2900° F. temperature immersion.

29. In this particular test series, the atmosphere in the furnace was air, with the sand specimen and test pin remaining in the furnace for 12 min. at temperatures as designated in Fig. 5.

30. Starting at the upper right hand side of the illustration with 1600° F., no penetration is noticeable. However, a thin coat of oxide is present on the test pins in the green and dry sand specimens, Fig. 5.

31. At a temperature of 1700° F., the first indication of penetration is evident. Veining or fissure type of defect was found, and this type of defect is clearly shown in Fig. 5 at 1700° F. and 1800° F.

32. Here is the first positive proof that metal need not be in the molten state to form defects such as "veining," "fissure," "cat whiskers," or "penetration" since they are found very prominently at a low temperature range,

Table 1  
SAND MIXTURE

	<i>Per Cent</i>
No. 17 Ottawa Sand, washed and dried, 45 A.F.A. fineness	95
Western bentonite	5
Moisture	2.5

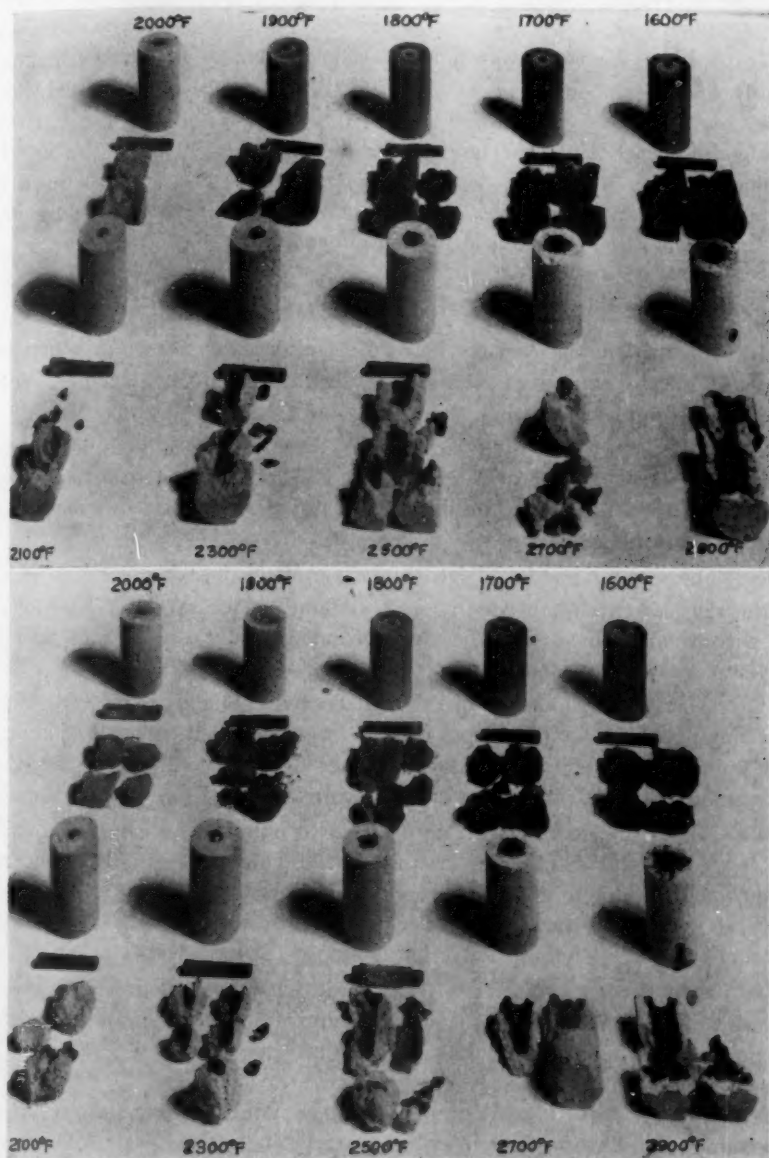


FIG. 5—PENETRATION TEST SERIES CONDUCTED AT VARIOUS TEMPERATURES WITH AIR AS THE FURNACE ATMOSPHERE. TOP—GREEN SAND SPECIMENS. BOTTOM—DRY SAND SPECIMENS. NOTE THAT TEST PINS WERE COMPLETELY ABSORBED AT THE 2900° F. TEMPERATURE.

for example, 1700° F. to 2000° F. It is possible that veining promotes penetration.

33. A study of Fig. 5 will show that the degree of penetration increases rapidly with a temperature rise. At 2700° F. the test pin is encrusted with a thick, hard layer of penetration, while at 2900° F., the test pin has completely disappeared into the sand under the oxidizing effect of the air. No particular difference in the degree of penetration is noticeable between the green and dry sand specimens. This is undoubtedly true since the green sand specimens were quickly dried in the dilatometer furnace.

#### PENETRATION AS AFFECTED BY OXYGEN, AIR, AND NATURAL GAS

34. Since the metal need not be in the molten state to form a penetration defect, it is very natural to assume that the metal surface is oxidized by the gas that surrounds the casting.

35. In Fig. 6 are shown cross sections of three sand specimens, all of which contain the same type of steel test pins and were subjected to a temperature of 2700° F. for 12 min. The difference was in the type of atmosphere in the dilatometer furnace.

36. The upper view in Fig. 6 shows complete absorption of the test pin by the sand when oxygen was the gas surrounding the sand. Where the test pin was originally located in the sand specimen is now a hole, since all of the steel was absorbed by the sand.

37. When the atmosphere in the furnace was changed to air, a less violent oxidizing agent containing 21 per cent of oxygen and 78 per cent of nitrogen, the amount of penetration was of a lesser degree, as shown in the center illustration (Fig. 6), than when oxygen was used.

38. Filling the furnace with natural gas to obtain a reducing atmosphere, the test pin is still in fairly good condition and no penetration is noticeable, as shown in the lower view in Fig. 6, after immersion for 12 min. at 2700° F. This is a good proof that the presence of oxygen in the face of a mold furnishes the motive power for the penetration defect of the oxide type.

39. As a further proof, tests were made whereby a neutral gas, such as nitrogen, was used to displace any oxidizing gases, such as oxygen, carbon dioxide, water vapor and air that might be present.

40. In these tests, it was found that no penetration defects were present, nor were any indications or tendencies to start penetrations present. Nitrogen-treated specimens showed some of the better surface finishes on the test pins after this severe penetration test.

#### *Steam in the Presence of Air or Oxygen Increases the Degree of Penetration*

41. The moisture contained in green molding sand, whether mechanically

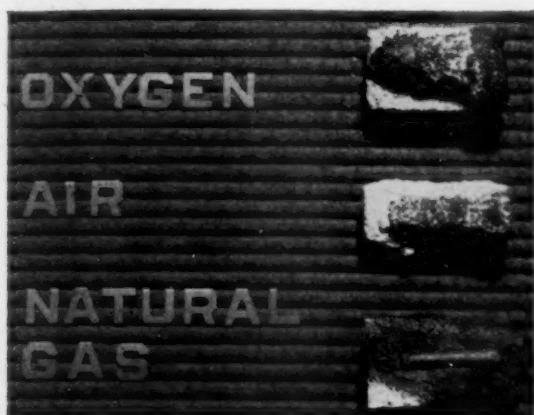


FIG. 6—PENETRATION IN GREEN SAND SPECIMENS UNDER VARIOUS ATMOSPHERES AT 2700° F. TEMPERATURE.

held, absorbed or chemically combined, produces a large quantity of water vapor in the hot portion of a mold.

42. In the case of dry molding sand, water is present in the chemically combined state, and also in small quantities as absorbed and mechanically held moisture which the sand picks up from the air as soon as it cools to room temperature.

43. Water may also be formed by intergaseous reactions within the mold; for example:



44. When the water vapor is converted to steam by the heat of the molten metal, the rate of the oxygen reaction with the metal is greatly accelerated. This is well illustrated by embedding steel pins in sand and heating at 2500° F. for a period of 12 min. In one case, let the atmosphere in the furnace be air, and in the other case, fill the furnace chamber with steam. The steel pin in the sand specimen which was subjected to the steam as atmosphere, will show easily twice the amount of penetration. Figure 7 gives a good visual demonstration of the power that heated water vapor has on increasing penetration.

#### DISPLACING OXIDIZING GASES WITH INERT GASES TO REDUCE PENETRATION

45. Atmospheres free of oxygen are very difficult to obtain in a mold. It is also difficult to have the mold atmosphere free of carbon dioxide, air and water vapor. One method that is available is to displace these oxidizing agents by an inert gas, such as nitrogen.

46. In the dilatometer penetration test and in limited mold tests made to date, nitrogen atmosphere in the furnace or mold produced the good surface finishes on the steel test pieces and the very small tendencies to penetration.

A test sample heated in nitrogen atmosphere at 2700° F. is shown in Fig. 8. Note the absence of penetration and the good finish on the steel specimen.

#### *Carbon Dioxide Atmosphere Increases Penetration*

47. Using the dilatometer penetration test and a 0.23 per cent carbon steel pin for the test specimen, a large amount of penetration is secured when the atmosphere surrounding the sand specimen and test pin is carbon dioxide (Fig. 8). The temperature of the dilatometer furnace was 2700° F. and the specimen remained in the furnace for 12 min.

#### MECHANICS OF PENETRATION AND VEINING DEFECTS

48. The authors are cognizant of the fact that their research work on penetration defect and mold atmosphere control is in its infancy, and much work remains to be done. The work to date indicates that the mechanics of penetration defects are as described in the following paragraphs.

49. Oxidizing gases, named in the order of their potency, as found or formed in a hot mold surface are oxygen, air, carbon dioxide and water vapor. Impurities present may catalyze the oxidization reactions.

50. In the determination of carbon in metal, where oxygen is passed over a metal in a combustion boat, the metal reaches a molten state at a very low furnace temperature, such as 1800° F., the oxidation of Fe, Si, Mn and C producing heat sufficient to melt the metal. The metal need not be in the molten state in a mold for the chemical reactions that produce penetration or veining defects.

51. The formation of these defects undoubtedly starts at a high temperature while the metal is in a molten state. Also, high temperatures accelerate the reaction. However, the formation may continue long after the metal solidifies. A thin outer skin of the casting is attacked by the oxidizing gases and the

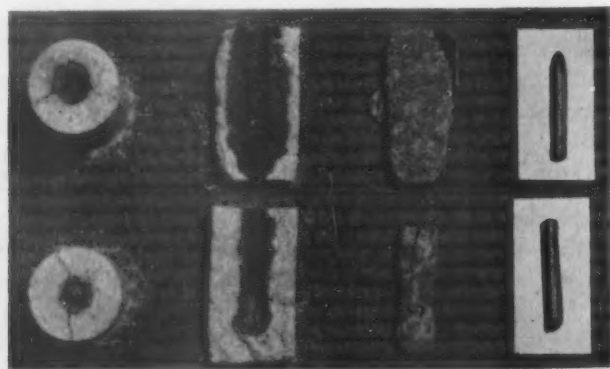


FIG. 7—PENETRATION IN SPECIMENS SUBJECTED TO STEAM (TOP) AND AIR (BOTTOM) ATMOSPHERES AT 2500° F. TEMPERATURE.



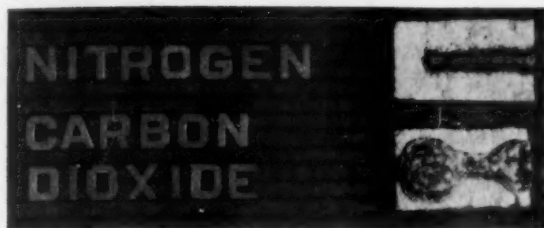
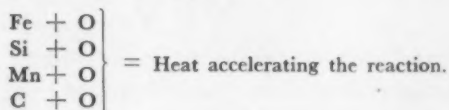


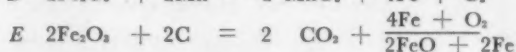
FIG. 8—PENETRATION IN GREEN SAND SPECIMENS SUBJECTED TO NITROGEN AND CARBON DIOXIDE ATMOSPHERES AT 2700° F. TEMPERATURE.

reaction continues until a temperature in the neighborhood of 1800° F. is reached.

52. The formation of the penetration and veining of the oxide types is similar to the Bessemer process. Where we have



Thus

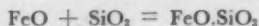


53. All of the foregoing reactions produce heat and, also, free iron, as is found in the penetration and veining defects. In addition, free oxygen and carbon dioxide are liberated, which keeps the reaction in process as long as some oxygen or other oxidizing gases are still present to attack the metal.

54. The iron oxide formed is very liquid, as is visually observed when the test method *B*, Fig. 3, is used and the specimen is placed in any of the fore-mentioned oxidizing atmospheres. A liquid iron oxide forms quickly at 2500° F. on the outside of the metal specimen, and is soaked up by the sand.

55. The ferrous oxide formed in equation *E* (paragraph 52) will attack the silica sand grains and form a fluid iron silicate, for example, possibly a ferrous metasilicate,  $2\text{FeO} \cdot \text{SiO}_2$ ,  $\text{FeO} \cdot \text{SiO}_2$ , or  $\text{FeSiO}_3$ . The ferric metasilicate  $\text{Fe}_2(\text{SiO}_3)_3$ , or the ferric orthosilicate  $\text{Fe}(\text{SiO}_4)_3$  and others also might be formed.

56. Work is in progress to identify the exact iron silicate or silicates that are formed. However, working from the equation *E*, which is the probable end product of the iron oxidation process in a mold, it may be concluded that the  $\text{FeO}$  formed will unite with the silica of the molding sand in the following manner:



57. The  $\text{FeO} \cdot \text{SiO}_2$  is one of the forms of ferrous metasilicate. It is a very fluid and penetrating type of iron silicate. The iron silicate formed, according to our tests, has a melting point of between 2100 and 2200° F.

#### *Composition of Penetration Defect*

58. A penetration defect which originated, not from a porous mold surface, but from oxidation of the metal, is composed as follows:

- (1) Metal
- (2) Carbon
- (3) Ferric oxide
- (4) Iron silicate
- (5) Molding materials
- (6) Ferrous oxide
- (7)  $\text{Fe}_3\text{O}_4$
- (8) Chemical elements of the metal

#### *Prevention of Penetration and Veining Defects*

59. The penetration defects that originate from a too porous mold surface due to coarseness of the sand, low flowability or soft ramming are corrected by reducing the green strength, grain size, or stiffness of the sand mixture. All of these factors will increase flowability of the sand mixture and give a continuous, uniform mold surface under normal ramming. In some cases, increasing or improving the ramming will eliminate penetration.

60. Veining may be caused by the early collapse of a core. In this case, retarding the collapse by increasing the life of a core through increasing the strength, reducing grain size, adding clay substance, adding iron oxide, adding silica flour, or by applying a wash will eliminate the veining defects.

61. However, there are many penetration defects and some veining defects that are caused by an oxidizing atmosphere. These are the most difficult to eliminate. The authors believe that means for the elimination of these defects will be found through the application of mold atmosphere control.

#### *Mold Atmosphere Control*

62. By mold atmosphere control is meant the elimination or absorption of the oxidizing atmosphere, such as oxygen, air, carbon dioxide and water vapor at the mold face.

63. Atmosphere control may be obtained either by the introduction of reducing or displacement gases in the mold, or by the formation of such gases within the mold surface through chemical additions to the sand or mold coatings.

64. Two other alternatives offer possibilities, and they are placing the mold in a vacuum or sealing the mold surface with a glaze that is impervious to gases, oxides and silicates at elevated temperatures.

65. Manifolds may be placed in the drag and cored portions of the mold to fill the pores of the mold with reducing gases, such as lithium, natural gas, various forms of petroleum gases, nitrogen and others. Such gases might be injected into the mold just before pouring and be allowed to flow while the casting is cooling.

#### TESTS OF FACING MATERIALS TO EVALUATE PROTECTIVE ATMOSPHERES FORMED

66. One of the avenues for attacking the problem of penetration is to study the facing materials used at the present time for eliminating or reducing penetration. The dilatometer penetration test method proved very efficient for this study.

67. Sand mixtures were prepared containing no. 17 Ottawa washed and dried silica sand bonded with 5 per cent of western bentonite. To each sand mixture was added 5 per cent by weight of facing material. Some 50 materials and chemicals were tested. In the succeeding paragraphs, some of the more interesting results will be discussed. It is appreciated that the 5 per cent by weight of many materials studied is too large an amount for commercial use. However, in the interest of having the evaluation made of equal concentration for comparison and convenience, the 5 per cent was used as a standard for the preliminary basic comparison work.

68. Specimens of each prepared sand were rammed and a 0.23 per cent carbon steel pin was inserted into each specimen. These specimens were then inserted in the dilatometer furnace and soaked for a period of 12 min. at a temperature of 2500° F.

69. The atmosphere in the furnace was air at the time the specimen was inserted in the furnace. The top of the furnace was sealed, and the bottom left open. Thus, each sand mixture created its own particular type of atmosphere.

#### PROTECTIVE ATMOSPHERES FORMED BY ADDITIONS OF VARIOUS FACING MATERIALS

70. With the commonly used facing materials may be grouped sea coal, coke and sugar. It is of interest to have a visual comparative evaluation of the protective atmospheres created by these three materials.

##### *Sea Coal*

71. In Fig. 9 is shown a top and cross-sectional view of the sand specimen after firing. A view is also shown of the test pin after the heat test. A close examination reveals that the sea coal addition kept the atmosphere sufficiently low in free oxygen to prevent complete combustion of the sea coal in the sand, as is shown by the black color of the interior of the sand specimen. A thin

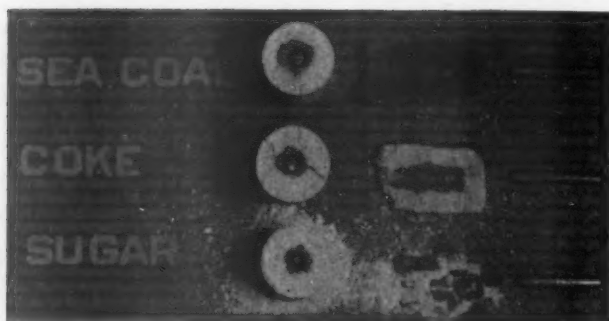


FIG. 9—EFFECT OF 5 PER CENT BY WEIGHT ADDITIONS OF FACING MATERIALS ON PENETRATION IN GREEN SAND SPECIMENS SUBJECTED TO AN AIR ATMOSPHERE AT 2500° F. TEMPERATURE.

outer layer of the sand specimen is oxidized, as is shown by the top view of the specimen. Oxidation leaves the sand white in color.

72. Sufficient oxidizing gases are present in the sea coal to cause the formation of a trace of some oxide penetration. Note the black oxide ring around the test pin on the top of the sand specimen (Fig. 9).

73. The steel test pin secured from the sea coal treated sand is of fair surface condition. On the surface of the pin are views of oxidization and adhering balls of impurities. The value of sea coal as a facing material undoubtedly can be improved by removal of the inert materials and high impurity content.

#### *Coke*

74. An examination of the coke treated sand and steel pin specimens indicates that the coke burns out more completely than does the sea coal. Dark areas of oxide penetration are visible in the cross-sectioned view, Fig. 9, of the sand specimen treated with coke. The appearance of the steel pin from this sand is superior to that of the pin obtained from the sea coal treated sand. More complete control of the rate of combustion is necessary to increase the facing value of coke. This material awaits further scientific development for greater use as a facing material.

75. Both sea coal and coke in their combustion create carbon dioxide and corrosive water vapors. This water vapor and the water vapor from the moisture in the sand should be absorbed by some chemical addition to the sand. Under such conditions, with controlled combustion rates, these materials offer much to the ferrous foundry industry. Sea coal and coke derive their facing value by the protective atmospheres created.

#### *Sugar*

76. A foundry facing material of long standing is sugar and molasses. The question often arises as to how sugar and molasses proved helpful on the mold or core surface. It is true that this material increases the surface dry strength

of the mold or core. However, in the light of this research work, the authors find that molasses and sugar prove beneficial in improving casting finish by the reducing atmosphere which they create. When sugar is partly burned, a very pure and fine particle-sized carbon is formed, which produces less oxide penetration and a better steel test pin surface than either sea coal or coke, when used in equal quantities. A study of Fig. 9 gives a good picture of this statement. Note the low retained strength of the sugar treated sand specimen. The cross-sectioned sand specimen consists of loose sand. Also, note the glaze secured on the thin layer of the penetration shell.

#### *Cereal Binders, Plastics and Borax*

77. Continuing our study of prominent facing materials, we enter into the field of cereal binders, plastics and borax. To represent the cereal binder group, the authors selected starch; for the plastic group of binders, urea was selected; and from the borax field, a boric anhydride was selected.

#### *Starch*

78. For a precise evaluation of these three materials, Fig. 10 is of aid. The sand treated with 5 per cent of starch produced a well-faced mixture. Only a thin oxide penetration scale was formed, and this was glazed. The test pin showed some grooving, but was of a good general appearance.

#### *Urea*

79. The amount of penetration resulting from the urea treated sand is slightly greater than that obtained from the starch treated sand. The steel

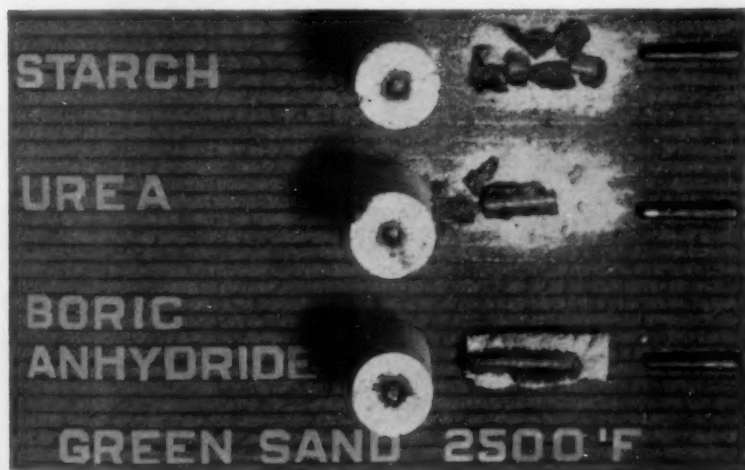


FIG. 10—EFFECT OF 5 PER CENT BY WEIGHT ADDITIONS OF FACING MATERIALS ON PENETRATION IN GREEN SAND SPECIMENS SUBJECTED TO AN AIR ATMOSPHERE AT 2500° F. TEMPERATURE.

test pin shows some signs of melting deformations and of grooving. A high degree of glazing was obtained, which indicates fluxing tendencies.

#### *Boric Anhydride*

80. The boric anhydride treated test samples show a considerable amount of fluxing, which would be prohibitive for sizeable ferrous castings. Its good use in the magnesium field is well demonstrated.

81. Both starch and urea may be considered as producing good protective atmospheres, but do not furnish the means of taking care of water vapor and carbon dioxide at the mold surface.

#### *Sodium Fluoride, Ascarite and Reduced Iron as Protectives*

82. The dilatometer penetration test method is quite severe, and only a very few of the large group of materials that were tested showed a fair amount of protective power.

83. Three materials, not used by the foundry industry as facing materials, which showed protective power are sodium fluoride, ascarite, and reduced iron powder (Fig. 11).

#### *Sodium Fluoride*

84. The sodium fluoride treated sand fluxed badly, produced a good glaze and the best surface finish of all materials tested to date. Sodium fluoride is a powerful reducing agent. It is poisonous and, since it fluxes so readily, its possible use in the foundry would require great care to avoid excessive fluxing on heavy sections of castings.

#### *Ascarite*

85. Ascarite, an excellent absorber of carbon dioxide, produced a good

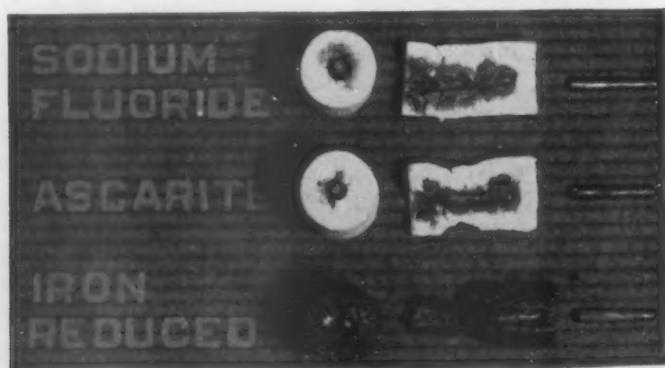


FIG. 11—EFFECT OF 5 PER CENT BY WEIGHT ADDITIONS OF PROTECTIVE MATERIALS ON PENETRATION IN GREEN SAND SPECIMENS SUBJECTED TO AN AIR ATMOSPHERE AT 2500° F. TEMPERATURE.



test pin. Like sodium fluoride, it fluxes badly, creating a high retained strength sand.

### *Reduced Iron*

86. Realizing that iron in the finely divided state will absorb oxygen readily at elevated temperatures, a sand prepared with 5 per cent of reduced iron was tested. Viewing the specimens in Fig. 11, it may be noted that the results were encouraging, and more will be stated concerning the possibilities of this material.

### *Wood Charcoal, Iron Chips and Potassium Ferrocyanide Produce Protective Atmospheres*

87. Three materials which are good reducing agents are wood charcoal, iron powder and potassium ferrocyanide. The wood charcoal absorbs oxygen due to its carbon content; the iron powder due to the ferrite, carbon, silicon and manganese; and potassium ferrocyanide due to the potassium. The test results secured from these three materials are shown in Fig. 12.

#### *Wood Charcoal*

88. The wood charcoal treated sand produced a test pin which is encouraging. The pin was not glossy, the surface being dull, but it was comparatively smooth considering the high temperature and the length of time at that temperature. No glazing was obtained, indicating that glazing is not imperative to prevent penetration. It is acknowledged that glazing, if gas and liquid tight, is protective and produces excellent results. Some glazing agent with wood charcoal offers a good possibility.

#### *Iron Chips*

89. It may be recalled that reduced iron produced test pins with fair surfaces. Using a more economical form of iron powder, the authors added 5 per cent by weight of fine cast iron borings to a sand mixture and obtained fairly good results. Sand prepared with iron borings should be used within a comparatively short period of time, for example, 3 hr., to prevent excessive rusting of the iron borings in the sand. Fine cast iron borings offer a very practical and economical facing material, and one worthy of varied foundry trial runs.

#### *Potassium Ferrocyanide*

90. The potassium ferrocyanide treatment is toxic, and is thus of research value only. From Fig. 12, it may be noted that this material fluxed badly, producing a high retained strength. The steel test pin produced is very good. The only trace of oxidation is at the exposed end of the test pin. Where the test mold or specimen is coped, this condition does not exist. The open test

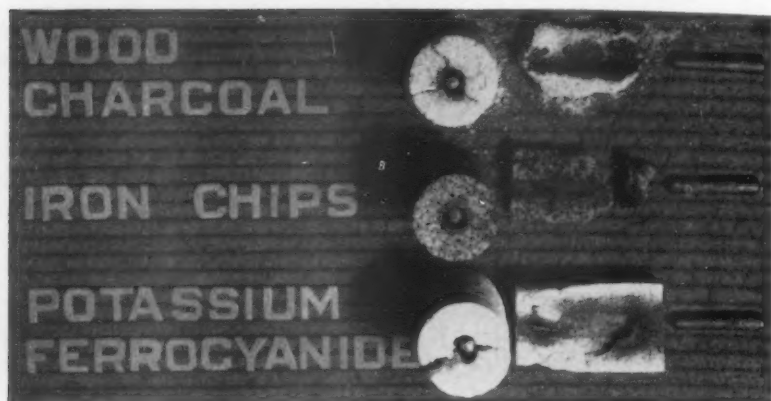


FIG. 12—EFFECT OF 5 PER CENT BY WEIGHT ADDITIONS OF PROTECTIVE MATERIALS ON PENETRATION IN GREEN SAND SPECIMENS SUBJECTED TO AN AIR ATMOSPHERE AT 2500° F. TEMPERATURE.

specimen method is more severe than the closed or coped test specimen method. The later method undoubtedly will prove advantageous for final evaluation of facing materials, while the open specimen method will be used for the preliminary research tests.

#### *Effect of Bentonite Additions on Penetration*

91. Bentonite of the western type produces a glaze on the face of a sand mold. It could be expected that additions of bentonite in large amounts would form a glaze of sufficient thickness to stop penetration. It may be noted (Fig. 13) that penetration is not affected materially by using bentonite in large quantities.

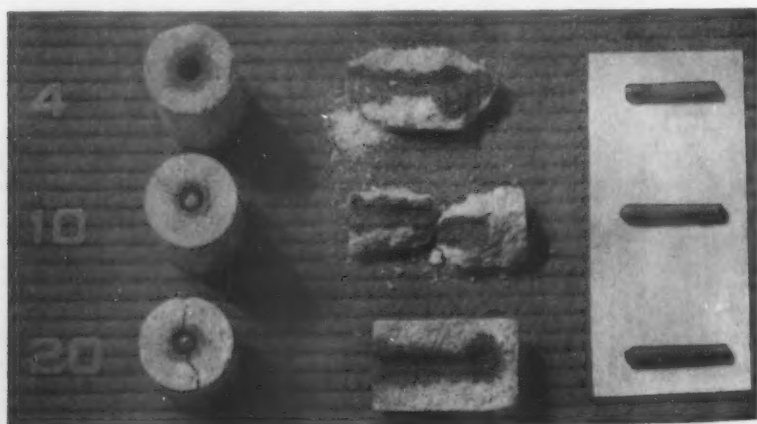


FIG. 13—ADDITIONS OF 4, 10 AND 20 PER CENT OF WESTERN-TYPE BENTONITE IN GREEN SAND SPECIMENS SUBJECTED TO AN AIR ATMOSPHERE AT 2500° F. TEMPERATURE SHOW NO EFFECT ON PENETRATION.

## CONCLUSIONS

92. The foundry facing materials used at the present time may have their protective power increased by compounding to absorb all oxidizing gases, for example, oxygen, carbon dioxide, air, water vapors and other impurities at the mold face.

93. Castings of both the ferrous and non-ferrous types should be cast in a protective, non-oxidizing or inert gas envelope to prevent deterioration of their surfaces in finish or chemical analysis.

94. The protective gas envelope may be obtained by the injection of reducing or inert gases into the molding sand or core of a mold previous to and while pouring the metal.

95. The protective gas envelope may be obtained by additions to the molding or core sand mixtures in the form of chemical liquids or solids, or by the addition of foundry facing materials, preferably compounded to be all-purpose.

96. Further research work along the line of developing an all-purpose facing material certainly will prove fruitful. Such a material should contain, for example, lithium or some other material that will absorb all the carbon dioxide, oxygen and moisture evaporated from the sand by heat, or moisture generated from the combustion of materials in the mold.

97. The creation of a vacuum within a mold before pouring to expel all oxidizing gases. The mold should be freed of all moisture and combustibles by firing before using.

98. The development of a material, the fluxing action of which at elevated temperatures will produce a gas- and liquid-tight seal at the mold surfaces—which is only partially obtained with the mold and core washes now in use—will prove very helpful in obtaining better casting finishes.

99. The material of this research work is presented at this time, before the entire project is completed, so that the findings to date may be put to practical use as soon as possible; and to speed up the development of this particular field of mold atmosphere by obtaining as large a group of workers as possible.

*(Discussion begins on following page.)*

## DISCUSSION

*Presiding:* WERNER FINSTER, Reading Steel Castings Div., American Chain & Cable Co., Reading, Pa.

*Co-Chairman:* H. RIES, Technical Director, Foundry Sand Research Project, Ithaca, N. Y.

J. B. CAINE<sup>1</sup> (*written discussion*): This paper has placed the discussor in the rather unenviable position of being forced, if for no other reason than that of self-defense, to disagree with the authors on a number of fundamental points, when at the same time he is in accord with the authors' views on a number of practical applications of the results of this paper. This point is important, for, even though an entirely new viewpoint, such as advanced in this paper, can be applied almost immediately to practice with beneficial results, it cannot be applied efficiently until the fundamentals in back of it are clearly understood.

One important point that must be kept in mind is the difference between metal and oxide penetration. It would seem that when a steel pin is heated in the dilatometer in contact with sand, penetration as described by the authors is oxide penetration in various degrees, depending on the atmosphere derived from either the sand itself, or by the introduction of a gas into the heating chamber of the dilatometer.

Mr. Dietert was kind enough to send some samples of this type of penetration to the writer for microscopic examination, two of which are shown in Figs. 14 and 15. This oxide penetration is entirely different than the metal penetration shown in Fig. 16, which is an example of adhering sand on a steel casting. The oxide penetration shown in Figs. 15 and 16 is black, does not reflect vertical illumination, and fluxes the sand grains, whereas metal penetration, as shown in Fig. 16, is white, reflects vertical illumination and does not flux the sand grains. When oxide penetration is analysed chemically, it is found to be an iron oxide-silicate; metal penetration always approaches, chemically, the composition of the casting.

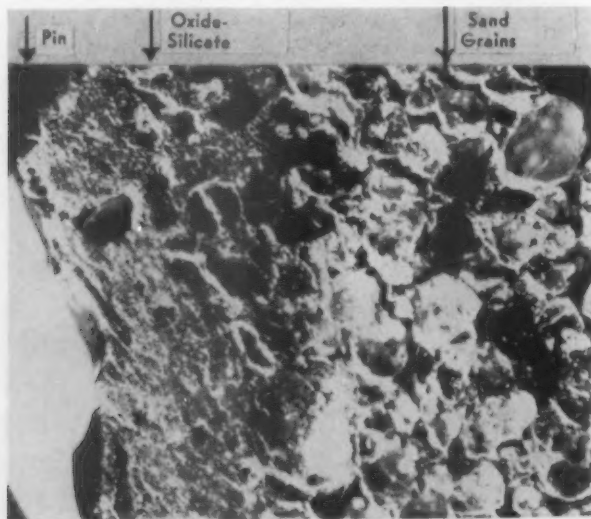


FIG. 14—MICROGRAPH SHOWING OXIDE PENETRATION WHEN SAND IS HEATED IN CONTACT WITH METAL PIN AT 2500° F. OBLIQUE ILLUMINATION. (X 25).

<sup>1</sup> Metallurgist, Sawbrook Steel Castings Co., Lockland, Ohio.

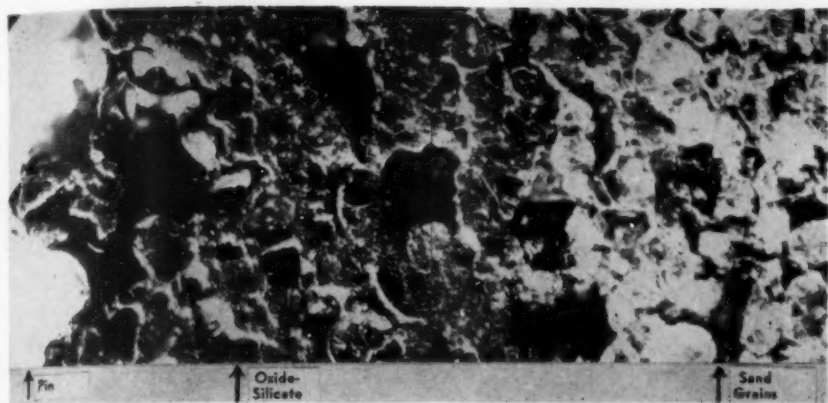


FIG. 15—MICROGRAPH SHOWING OXIDE PENETRATION WHEN SAND IS HEATED IN CONTACT WITH METAL PIN AT 2900° F. OBLIQUE ILLUMINATION. (X 25).  
(slightly reduced in reproduction).

The difference between these two types of penetration is shown more clearly in Fig. 17. This is a specimen of adhering sand heated to 2200° F. in the dilatometer, in air. The steel that originally had permeated the sand has been oxidized in the dilatometer, forming the outer surface of iron oxide-silicate. The sharp boundary between the original metal penetration and the oxide-silicate at the surface, formed in the dilatometer is significant.

Even though the writer has always seen adhering or "burnt on" sand in practice associated with metal penetration, not oxide penetration, this does not mean that mold atmosphere or mold gas is not important in practice. From a practical viewpoint, the exact mechanism is secondary, for almost any addition to the sand which will form a gas will form a reducing gas. Such a gas will minimize metal penetration as well as

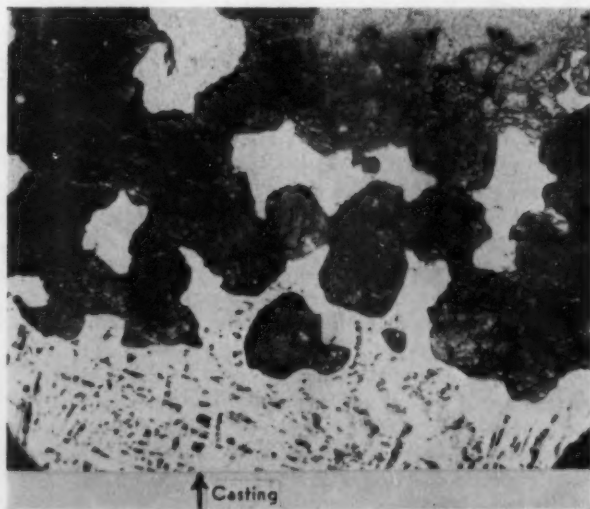


FIG. 16—MICROGRAPH SHOWING METAL PENETRATION, ADHERING SAND ON A STEEL CASTING. VERTICAL ILLUMINATION. (X 25).

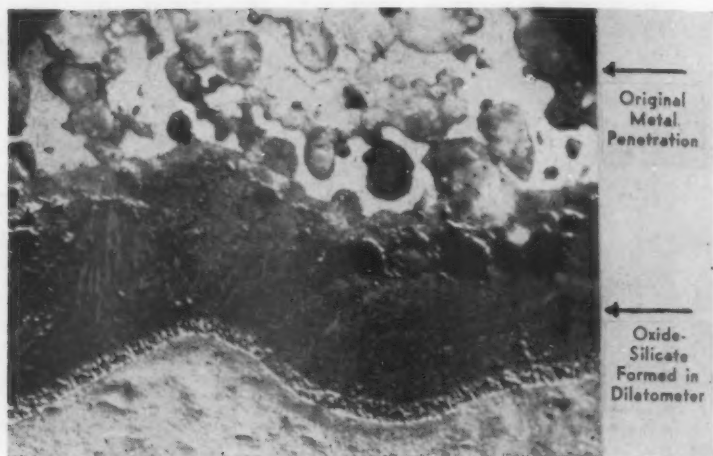


FIG. 17—MICROGRAPH SHOWING EXAMPLES OF METAL PENETRATION AND OXIDIZED METAL PENETRATION. VERTICAL AND OBLIQUE ILLUMINATION. ( $\times 25$ ).

oxide penetration. Perhaps the mechanism that decreases metal penetration is purely mechanical (pressure), rather than chemical, but the end result is the same.

The question boils down to—do we have an increase in iron oxide at the sand-metal interface similar to that shown in the dilatometer when liquid steel comes in contact with the sand? We do, but it varies widely, from a fraction of one per cent to over 10 per cent. The reason for this variation must be found and, what is just as important, the time at which iron oxide combines with the sand must be determined. If iron oxide forms and combines with the sand while it is in contact with liquid steel, that means one thing; if it forms only after the steel solidifies, it means something entirely different. It is hoped that this point is clarified in the near future, as it is important, not only to this subject, but to all high temperature work. If the analysis of the sand does change when in contact with metal, this point must be taken into consideration in all high temperature work on sands.

MR. DIETERT (*answer to Mr. Caine's written discussion*): The authors appreciate Mr. Caine's written discussion and concur with him in that the material presented deals with the oxide type of penetration, as stated in paragraph 10 of the paper.

Undoubtedly, many penetration defects start in the mold as an oxide penetration due to the oxidation of the outer metal skin of the casting. This superheats the outer layer or skin of the metal in addition to forming an oxide that attacks and wets the sand grains, forming an iron-silicate flux.

This iron silicate in a penetration defect has a melting point of between 2100 and 2200° F. So, at the metal pouring temperature plus some superheat, this iron silicate is very fluid.

As this iron silicate and iron oxide penetrates through the sand, some reducing gases, for example, from a cereal binder, are encountered that will convert some of the metal oxide to free metal, as viewed in so many of the penetration defects. This theory may be well demonstrated by first oxidizing the surface of a piece of finished steel in a furnace and then injecting a reducing gas. The metal oxide scale will be reduced to steel and weld itself to the steel part.

Penetration defects which are high in free metal, probably from reconverted oxides, weld themselves to the casting, while those low in free metal generally peel freely.



Thus, a limited or controlled oxidation may offer a solution to secure a thin penetration peel of metal oxides only.

It is the authors' belief that oxide penetration, as shown by the dilatometer test described, precedes many penetration defects, with the exception of the metal penetration defect described in paragraph 9 of the paper.

Tests have clearly shown that iron oxides are formed while the metal is liquid and after the metal solidifies, provided that oxidizing gases such as air, oxygen, carbon dioxide and superheated steam are present.

The authors wish to acknowledge the many stimulating and helpful aids that Mr. Caine has rendered in this research project. Continued efforts will, undoubtedly, uncover the detailed fundamental mechanics that are present in a mold or core face to cause the oxide-metal penetration defects.

H. F. TAYLOR AND R. E. MOREY<sup>2</sup> (*written discussion*): The authors are to be congratulated for this fine paper. It describes interestingly and in complete detail a principle and theory of sand behavior which strikes at the very heart of good castings. There is danger, since the test appears at first glance to be only an interesting laboratory development, that foundrymen will underestimate its usefulness in solving the practical problems of adhering sand.

At the Naval Research Laboratory we have been working with this test for more than a year and, while we do not understand all the factors involved, we are finding it a very powerful tool for predicting the behavior of sands in contact with molten metals and for improving foundry operating techniques. It is believed that the test must be tried, or at least seen in operation, to be really appreciated.

The results of our tests check accurately with those of the authors and, at one time or another, we have duplicated all except those employing coke, sugar, ascarite, sodium fluoride and similar compounds. Our theories regarding the sand-metal interface reactions are not as completely determined as are those of the authors, but x-ray, petrographic, and chemical studies are being made as rapidly as possible. We have made several experiments with neutral and reducing gases, both in the sinter pin test and in actual practice, and find that it is possible to completely prevent the formation of the fused, black layer of sand. It is not certain that this is fully desirable because in the absence of this condition the sand sometimes sticks tightly to the casting and is difficult to remove. In general, a good fused layer of the proper thickness gives smooth, easily cleaned castings. In short, the clay and sand grains are either properly fused into a dense, continuous layer which prevents metal penetration, or there is danger that the metal will flow between and around the grains causing them to stick to the casting.

An interesting experiment which can be made in any foundry is to pour two identical steel castings in new facing sand, bleed the metal out of one at the end of 30 sec. (or at such time as a wall of metal about 1/32 to 1/16 in. has formed) and allow the other to freeze in the mold. It will be observed that the sand sticks tightly to the former (no black layer) and peels rapidly from the latter (definite black layer).

The foregoing test served to show that the formation of the "peel" is not a direct result of the presence of liquid steel as such, but that it forms at some time after solidification of part or all of the casting. This is why a pin of solid steel can be used in a sand specimen at temperatures considerably below the melting point of steel to duplicate mold conditions at the time of casting.

Although far from complete at the present time, our experience with the sinter pin test has led us to certain theories regarding the formation of the fused, black layer at the mold-metal interface. The following phenomena are believed to occur:

The organic binders burn out. As the temperature rises the clay softens and ultimately melts. At the same time the surface of the steel is oxidized to

<sup>2</sup> Naval Research Laboratory, Washington, D. C.

iron oxide, probably as  $\text{FeO}$ , by the oxygen present in the interstices between the sand grains, or from a breakdown of water vapor or other gases which may be present. Clay, being a finely divided alumina-silica complex, melts readily and forms a liquid glass into which the iron oxide and the silica of the sand grains dissolve forming a complex compound of  $\text{FeO-Al}_2\text{O}_3\text{-SiO}_2$ . This is extremely fluid material and normally soaks into the sand, often for considerable distances. However, in some cases, it has flowed through thin cracks in the specimen onto the supporting post at temperatures as low as  $2000^\circ\text{F}$ .

The equilibrium diagram for this system is shown in Fig. 18. The composition of the black layer will probably vary somewhat over its thickness, being higher in iron oxide near the casting and higher in silica at the other edge.

We do not, at the present time, believe that the term "oxide penetration" as used by the authors adequately describes the phenomenon under discussion. For example, in paragraph 10, the authors refer to oxide penetration as being a "mixture of metal and oxides of the metal." We have never found any indication that metal, per se, pene-

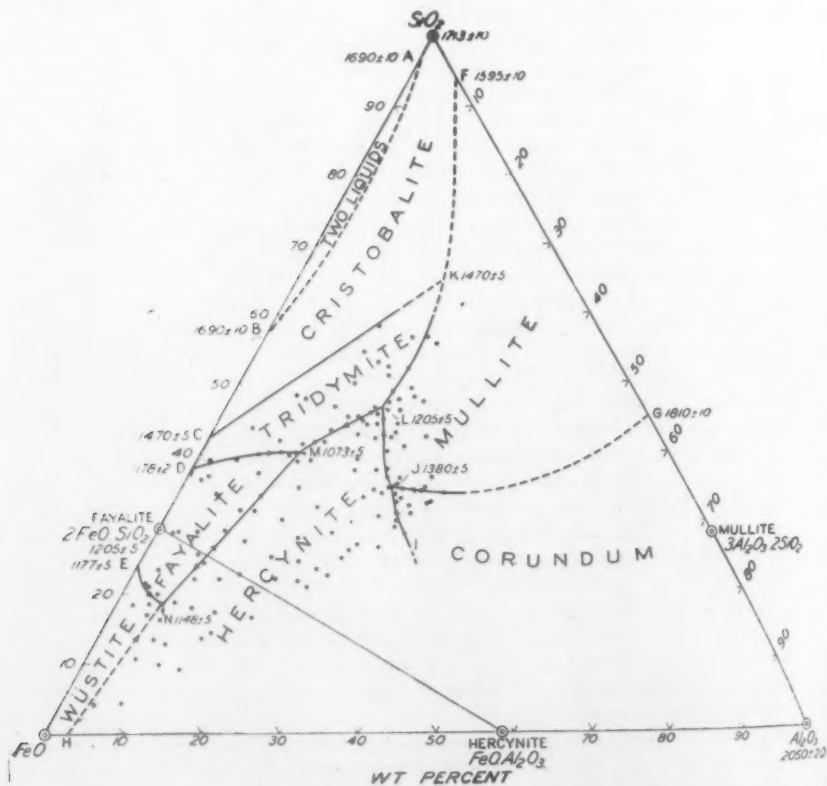


FIG. 18—EQUILIBRIUM DIAGRAM\* OF THE SYSTEM  $\text{FeO-Al}_2\text{O}_3\text{-SiO}_2$ . THE DIAGRAM IS WITHOUT ISOOTHERMS AND SHOWS THE FIELD OF STABILITY OF CRYSTALLINE PHASES IN CONTACT WITH LIQUID.

\*Schairer, J. F., "System of  $\text{CaO-FeO-Al}_2\text{O}_3\text{-SiO}_2$ : I, Results of Quenching Experiments on *Four Joins*," JOURNAL, American Ceramic Society, vol. 25, no. 10, pp. 241-274, June 1, 1942.

trating into the sand was an essential feature, or even an existing feature, of the sinter pin test.

A paragraph describing the genesis of the test is interesting for two reasons; first, it indicates the dividends which may result from a careful study of some of the seemingly simple and unimportant phenomena that are observed regularly in the foundry. For example, we had under consideration at this laboratory a problem of investigating the causes and nature of peculiar slag-like defects found on the cope surfaces of castings. It appeared that the cause was actually slag washed in with the metal, slag formed as the molten metal washed over the sand, or slag forced out of the liquid as it cooled during filling of the mold. However, one day a fused, black layer of sand was picked from the surface of a steel chill plate which had been used on a large casting. The slag-like defect, identical to that found on the cope surface of castings, was observed even though no molten metal had access to this area. It is obvious how the sinter pin test evolved from this observation, and it is also obvious that the solution of the "cope-defect" does not lie in a study of the molten metal as we had at first supposed.

Our interest in mold atmosphere control was aroused by a similar chance observation. During a discussion of lost wax techniques as applied in dentistry, the operator mentioned that he often mixed fine copper shot in his investment to produce bright castings of vitallium. This was a very practical method for removing oxygen as the mold was heated to casting temperature.

The fields of mold atmosphere control and mold-metal interface reactions have hardly been scratched, and it is hoped that the authors' fine paper and our own brief discussion will serve to stimulate further work along these lines to the end that the perfect steel casting will one day be made.

MR. DIETERT (*answer to Messrs. Taylor and Morey's written discussion*): The written discussion of Messrs. Taylor and Morey adds materially to the authors' paper on mold atmosphere control. The authors again wish to express their appreciation for the fine co-operation they have received from the Naval Research Laboratory.

The term "oxide penetration" was used in the paper to forcibly differentiate between the penetration defect where the molten metal flowed freely into large open crevices in the mold face, from a penetration defect where the mold face did not present any large crevices. We agree with the desire for a better terminology for this so-called "oxide penetration," but for the time it seems adequate until a better term is developed.

When the  $\text{FeO}$ , as formed by the oxidization of the metal on the mold face, comes in contact with a melt of  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  of the mold face, the  $\text{FeO}$  thins the melt appreciably and one no longer has a viscous glaze on the mold face.

## Radiographic Specifications and Standards for Naval Materials†

BY CLYDE L. FREAR\*, WASHINGTON, D. C.

### Abstract

*The Navy Department specifies radiographic examination of steel castings subjected to high pressure steam and for important hull castings. The use of this method of inspection has resulted in a distinct improvement in the soundness of castings which enter into the construction of hulls and machinery. Specifications have been issued to cover the Navy requirements as to radiographic technique. To aid in the interpretation of radiographs and decision as to the necessity for repair of defects, the Bureau of Ships has issued "Radiographic Standards" showing the acceptability of typical defects occurring in various classes of castings used in ship construction.*

1. Radiography as a method of inspection was first used by the Navy in 1930 for inspecting welds in boiler drums. The specifications for these boiler drums required radiographic inspection of all longitudinal and circumferential joints and were incorporated in a series of preliminary specifications of the Bureau of Engineering. This requirement was subsequently adopted for all welded pressure vessels, both fired and unfired, for high pressure service.

2. The first application of radiography to steel castings occurred at the Norfolk Navy Yard in the same year when the Bureau of Construction and Repair authorized the Naval Research Laboratory to make a radiographic exploration of a sternpost casting which had failed on the USS CHESTER. This examination showed the existence of a large hot tear and numerous shrinkage defects, the laboratory report including a number of comparisons between gamma-ray indications and the actual appearance of the defects as shown by sectioning and excavation.

3. In 1931 the Bureau of Construction and Repair and Bureau of Engineering requested the Norfolk Navy Yard to subject important castings for other ships under construction at that time to radiographic inspection. The yard concluded that the process was useful in locating gross defects in castings and also for assisting the foundry in developing its technique, and decided that the process would be used regularly in the production department.

†Published by permission of the Navy Department.

\*Engineer of Materials, Bureau of Ships, U. S. Navy.

NOTE: This paper was presented at an Inspection of Castings Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

4. Since that time, radiographic inspection has developed to such a point that it is now required on all important and highly stressed hull castings, and on all machinery castings which are subjected to superheated steam. The material specifications required radiographic examination as a method of inspection for the following classes of castings:

- Main and intermediate shaft struts.
- Rudder castings.
- Rudder skegs.
- Rudder posts.
- Stern posts.
- Skegs.
- Stern tubes.
- Turret roller paths.
- Turret holding-down clips.
- Turret buffer castings.
- Main propulsion turbines, including all control valves.
- Main steam line valves and fittings.
- Superheater valves and fittings.
- Boiler stop valves.

Radiographic examination of castings other than those listed may be required, provided that such examination is specified in the contracts or purchase orders. In addition, radiographic examination is required for welds in steam piping and for all assembly welds in steel castings; also, to determine the effectiveness of repair of major defects in castings which fall within the class requiring radiography as a method of inspection.

5. As a result of these requirements, four Navy yards have been furnished with million-volt X-ray equipment for the examination of heavy castings and structures. All yards also have 220-Kv. mobile X-ray units, and a number of yards have lower voltage units, chiefly for the examination of welds in high-pressure piping. In addition, each yard has sufficient radium available to conduct examinations where the use of X-rays is not practicable.

6. It is not unusual to find that beneficial inspection methods are resisted by the people who stand to gain most by their use, and radiographic inspection is no exception. The steel foundry industry, in general, resisted its use, and some resistance still persists. The chief causes of such resistance are:

- (a) Inertia on the part of manufacturers to use a new tool or technique.
- (b) Cost of radiographic inspection.
- (c) The fear that serviceable castings will be rejected due to insufficient knowledge or experience in the interpretation of radiographs.

7. Often those who were loudest in their objections have since learned to recognize radiography as a distinct advantage. A number of foundries have installed radiographic equipment, not only as a method of inspection but as a means of improving foundry methods by locating and eliminating these defects. The procedure of making a pilot casting, which is subsequently sectioned in the

hope that all of the defects will be found and the molding technique corrected, always has been an expensive process. The cost of this procedure might be absorbed if sufficient castings of the same design are produced, but is almost out of the question if only one or a few castings are made. By the use of radiography, internal defects can be located and, under present standards, the casting, if found to be defective, can be repaired and placed in service.

8. In order to eliminate the objection of high cost, the Bureau of Construction and Repair and the Bureau of Engineering in 1939 issued a letter setting forth the following policy, which was continued after combination of these bureaus into the Bureau of Ships:

"(A) When radiographic inspection is specified by the contract or order and unless the contract or order specifies that radium is to be furnished by the contractor, radium shall be made available by the inspector in charge for the examination of castings in order to determine the nature and extent of internal defects and to aid in determining the subsequent elimination of such defects. Under this classification, the government will supply the radium and radiographic accessories, will supervise the radiographic technique, and will be responsible for the development of the films. The contractor may, if he so desires, develop the films under the supervision of the inspector in order to expedite the fulfillment of the contract. The negatives will be the property of the government.

"(B) Where radiographic inspection is not specified by the contract or order, but the inspector believes that it is to the best interest of the government to conduct radiographic examination of finished castings before final assembly, and the contractor agrees to this inspection; or when such radiographic examination is required to prove the effectiveness of weld repairs, radium not being used under classification (A) will be made available for this purpose through the office of the inspector. The furnishing of accessories and films and the development of films will be the responsibility of the contractor. The radiographic technique and the development of films shall be under the supervision of the inspector who may require one negative of each weld repair to be sent to the bureau concerned for final approval, such negatives to remain the property of the government. Radium furnished under this classification shall be subject to withdrawal at any time without advance notice as the exigencies of classification (A) require.

"(C) When radium is available after the conditions of classifications (A) and (B) have been fulfilled, this radium may be furnished through the office of the inspector for use in the examination of Navy castings for the improvement of foundry technique and to improve the general quality of castings. Under this classification, the furnishing of accessories and films, and the development of the films shall be the responsibility of the contractor or subcontractor. The negatives shall remain the property of the contractor or subcontractor. Radium furnished under this classification shall be subject to withdrawal at any time without advance notice as required by classifications (A) or (B). Radium owned by the Navy shall not be used to inspect castings other than those for government use."

#### REQUIREMENTS

9. In order to standardize, insofar as possible, the conditions under which radiographic examination is conducted by inspectors and by contractors, the



Bureau of Ships has issued "*General Specifications for Inspection of Material; Appendix II—Metals; Part F—Radiography; Section F-1, Definitions and Radiographic Requirements*," dated March 1, 1942 (Appendix I), which requires that plans for castings, radiographic examination of which is specified, be forwarded to the bureau for marking with symbols showing areas which are to be radiographed, preferred location of films, location of radium if necessary, also the casting classification for application of radiographic standards. The radiographic symbols used are in accordance with "*General Specifications for Inspection of Material; Appendix II—Metals; Part F—Radiography; Section F-2; Radiographic Symbols*," dated August 1, 1942 (Appendix II). The radiographic symbols added by the bureau are then incorporated by the designer in the next alteration of the plan, thus becoming a permanent record for the use of everyone concerned in producing and inspecting the part. In marking a plan and the selection of radiographic locations, the bureau takes into account the stresses to which the part will be subjected in service, and the liability to defects of a certain type as affected by the design. When a manufacturer has definitely shown that his castings are free from defects in all or certain locations as evidenced by radiography, the specifications permit, except for occasional spot checks, elimination or reduction in the amount of radiographic inspection on subsequent castings of the same design.

10. Either gamma rays or X-rays may be used in the examination of castings. However, it should be borne in mind that the successful inspection of castings having non-uniform sections, with low voltage X-rays (440-Kv. max.), is very difficult and often very time consuming unless the manufacturer is provided with a number of accessories for blocking thin sections. There is also a definite limit to the thickness of section which X-rays will penetrate, the heavier sections requiring higher voltage equipment. The use of radium or million-volt X-rays is almost a necessity, therefore, when radiographing heavy sections or locations in which there is a large variation in section thickness. However, the use of X-rays is recommended for radiographing high pressure pipe welds, as radium fails to indicate many small defects which might be injurious in service.

#### PROCESS APPROVAL

11. Much production radiography is performed by industrial radiographic laboratories. While these private laboratories do excellent work, much of their inspection work is repetitive, using a technique which has been worked out over a considerable period of time. Radiographic inspection of ship castings, on the other hand, often requires an entirely different technique. After a number of failures to obtain the desired results, the Navy Yard, New York, designed a test block for radiographic process approval. Industrial radiographic laboratories are required to pass this approval test before they are approved for radiographing castings under the cognizance of the Bureau of Ships. The test blocks are made in one, three and five-in. thicknesses of steel. There are also available one-in. test blocks of bronze and aluminum. These blocks are

made available by the naval inspector to any laboratory which desires to have its radiographic technique approved. It has been the practice to give no instructions with regard to the actual technique to be used in the test, each laboratory using its own special technique, the only requirement in this connection being that the test block must be radiographed with a single exposure. After processing, the films are turned over to the inspector who forwards them to the bureau via the Navy Yard, New York. If the laboratory fails to qualify the first time, the reasons for such failure are reported and a second trial is permitted. Upon passing the test, the laboratory is approved for radiographic inspection of Bureau of Ships castings within the range of its equipment.

12. As a constant check upon the radiographic technique, the use of penetrameters is required, although the Bureau of Ships is extremely liberal in the type of penetrameter which may be used. The specifications (Appendix I) show several suggested designs. Other designs may be used provided that the penetrameter is capable of indicating 2 per cent thickness sensitivity.

#### RADIOGRAPHIC STANDARDS

13. Replies to early questionnaires distributed by the A.F.A. Committee on Radiography of Steel Castings indicated that producers were not in favor of radiographic examination as a method of inspection until suitable standards of acceptability were issued. It is easy to understand this reluctance as, without such standards, a casting might possibly be rejected for slight defects which would in no way affect its serviceability. Accordingly, a proposed set of radiographic standards for steel castings for steam pressure service was prepared by the Bureau of Engineering in 1936. Copies were sent to all Navy Yards, interested inspectors and contractors. In general, the replies from commercial foundries were unfavorable, while those from consumers, such as Navy Yards and private shipbuilders, indicated that radiographic inspection was desirable. A few commercial foundries accepted contracts in which radiographic inspection was required. "*Gamma-Ray Radiographic Standards of the Bureau of Engineering for Steel Castings for Steam Pressure Service*" were issued under date of September 1, 1938. These standards contained negatives showing acceptable, borderline and unacceptable gradations of all types of defects usually found in steel castings. In the case of unacceptable defects, examples were shown where repairs by welding would be permitted and also of those cases where the extent of the defect was sufficiently great that no repairs would be permitted.

14. These standards were in effect until July, 1942, and were found to be a great aid in allaying fears which the foundries had of accepting radiography as an inspection method. Concurrent with the adoption of these standards, a training program was instituted to train inspectors in radiographic technique and especially in the interpretation of defects as revealed by the radiographs. However, in the meantime the vastly increased shipbuilding program necessitated the procurement of large numbers of hull and other structural castings

which would be subjected to radiographic examination but for which there were no standards of acceptability in existence. Accordingly, early in 1940 the preparation of such standards was begun by requesting Navy Yards and some private manufacturers to forward to the bureau radiographs which showed various types and extent of defects. As X-rays were finding increasing use in the examination of castings, and as gamma-ray standards put the use of X-rays at a disadvantage, it was desired to have any new standards cover the use of both X-rays and gamma-rays. After nearly 2 years, a large number of radiographic negatives had been collected which could be arranged into a set of standards which would serve for X-ray or gamma-ray inspection of both pressure and hull castings.

15. Castings were divided into five classes, as shown in Table 1, depending on their wall thickness and service requirements with regard to impact resistance, pressure requirements and methods of loading. Table 2 was then prepared, and radiographs were selected and arranged to show acceptable, borderline and unacceptable defects for each class of casting. As finally released on July 1, 1942, they are titled "*Radiographic Standards for Steel Castings—Bureau of Ships—Navy Department.*" Attention is invited to the fact that these standards are applicable only to castings under the cognizance of the Bureau of Ships and cover hull and machinery castings. Their use in the inspection of castings for ordnance aircraft and other special classes of castings must be specifically arranged with the activity concerned.

16. The "*Standards*" contain 31 plates, each plate having a gamma-ray and an X-ray radiograph of the same defect located as nearly as practicable

Table 1

## CLASSIFICATION OF CASTINGS FOR APPLICATION OF RADIOGRAPHIC STANDARDS

Class	Casting
1	High pressure valves and fittings (wall thickness less than 1 in.) Super-heater fittings. Boiler stop valves. Machinery castings subject to fatigue or impact stresses (wall thickness less than $\frac{1}{2}$ in.).
2	High pressure turbine casings. Steam chests. Turbine throttle valves. High pressure valves and fittings (wall thickness 1 in. or greater). Low pressure valves (wall thickness less than 1 in.). Machinery Castings (wall $\frac{1}{2}$ in. or greater).
3	Low pressure turbine casings. High pressure turbine exhaust casings. Low pressure end of high pressure turbine. Low pressure valves (wall thickness 1 in. or greater). Machinery castings not subjected to steam pressure.
4	Hull castings less than 3 in. in thickness—subjected to high service stresses. Machinery castings not subjected to impact stresses or vibration.
5	Hull castings 3 in. or more in thickness and subject to high service stresses.

Table 2

RADIOGRAPHIC STANDARDS						
Type of Defect	Class Plate	Class 1	Class 2	Class 3	Class 4	Class 5
Gas and Blow-holes	A1	Borderline	Acceptable	Acceptable	Acceptable	Acceptable
	A2	Unacceptable	Borderline	Acceptable	Acceptable	Acceptable
	A3	Unacceptable	Unacceptable	Borderline	Acceptable	Acceptable
	A4	Unacceptable	Unacceptable	Unacceptable	Borderline	Acceptable
	A5	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline
	A6	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Sand Spots and Inclusions	B1	Borderline	Acceptable	Acceptable	Acceptable	Acceptable
	B2	Unacceptable	Borderline	Acceptable	Acceptable	Acceptable
	B3	Unacceptable	Unacceptable	Borderline	Acceptable	Acceptable
	B4	Unacceptable	Unacceptable	Unacceptable	Borderline	Acceptable
	B5	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline
	B6	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Internal Shrinkage	C1	Borderline	Acceptable	Acceptable	Acceptable	Acceptable
	C2	Unacceptable	Borderline	Acceptable	Acceptable	Acceptable
	C3	Unacceptable	Unacceptable	Borderline	Acceptable	Acceptable
	C4	Unacceptable	Unacceptable	Unacceptable	Borderline	Acceptable
	C5	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline
	C6	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Hot Tears	D1	Unacceptable	Unacceptable	Unacceptable	Borderline*	Acceptable
	D2	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline*
	D3	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Cracks	E1	Unacceptable	Unacceptable	Unacceptable	Borderline*	Acceptable
	E2	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline*
	E3	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Unfused Chaplets	F1	Unacceptable	Borderline	Acceptable	Acceptable	Acceptable
	F2	Unacceptable	Unacceptable	Borderline	Acceptable	Acceptable
	F3	Unacceptable	Unacceptable	Unacceptable	Borderline	Acceptable
Internal Chills	G1	Unacceptable	Unacceptable	Borderline	Acceptable	Acceptable
	G2	Unacceptable	Unacceptable	Unacceptable	Borderline	Acceptable
	G3	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline
	G4	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable

\*Acceptable only when angle between the defect and the direction of the principal stress is not greater than 20°.

in the same area on the two radiographs. All X-ray radiographs were made using 220-Kv. X-ray equipment. In making the original radiographs, a technique was used which would produce a negative duplicating the results which would be obtained by radiographers in the field rather than obtaining negatives as nearly perfect as possible.

17. Every method of duplication which came to the notice of the bureau was tried, including negative paper reproductions from intermediate positives and several half-tone processes, but none of these showed the defects as they would appear by viewing a negative by transmitted light. It was finally determined that the only satisfactory method of reproduction would be actual photographic negatives made by contact printing from an intermediate positive produced by projection methods. The illustrations accompanying this paper (Figs. 1 to 6), being half tones, do not show the detail present in the original standards and are shown only to illustrate the standards and *must not be used as standards*.

18. In general, the "Standards" are very strict for Class 1, covering thin-wall castings which are subjected to high temperature and pressure, also thin-wall castings subjected to fatigue or impact stresses. Class 2 permits considerably more leeway in the allowable defects, and this leeway increases as the class number increases. It should be noted that no hot tears or cracks are permitted in Classes 1 to 3, inclusive, which include all pressure castings and most machinery castings. In hull castings (Classes 4 and 5) hot tears and cracks are permitted only if the angle between the defect and the direction of principle stress is not greater than 20 degrees.

19. When the radiograph shows but one type of defect which is equal to or better than the borderline standard, the corresponding portion of the casting shall be considered as acceptable without repair. If the defects are more numerous than indicated by the borderline standard, the casting shall be rejected. When a single radiograph shows more than one type of defect, the following procedure shall be used in judging the acceptability:

(a) When one type of defect predominates and the other types are equal to or better than an acceptable (not borderline) standard for their particular class, the borderline standard of the predominating defect shall govern without regard to the other types of defects.

(b) When two or more types of defects are present to an extent equal to the borderline standard for each type, all borderline defects shall be considered unacceptable and the casting shall be rejected.

20. In general, there will be no limit in regard to the extent of acceptable defects throughout the area on a particular casting corresponding to the casting classification, provided that no 5x7-in. area throughout the section contains defects in excess of those indicated on the borderline standard. In general, the amount of welding which the naval inspector will authorize will depend upon whether the manufacturer decides that it is more economical to replace or repair the casting.



FIG. 1—BORDERLINE ACCEPTABLE GAS CAVITIES IN CLASS 3 CASTINGS. ORIGINAL X-RAY NEGATIVE  
5 BY 7 IN.



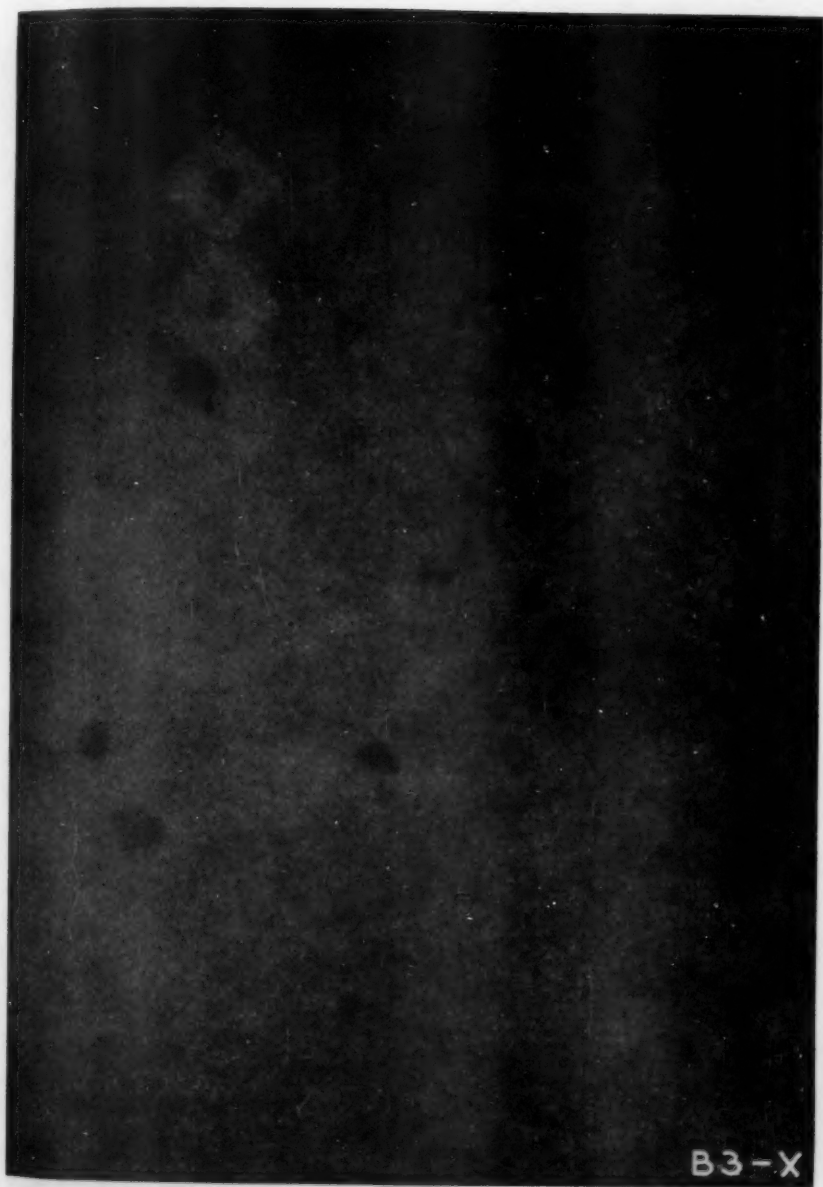


FIG. 2—BORDERLINE ACCEPTABLE SAND IN CLASS 3 CASTINGS. ORIGINAL X-RAY NEGATIVE 5 BY 7 IN.



FIG. 3—BORDERLINE ACCEPTABLE SHRINKAGE IN CLASS 3 CASTINGS. ORIGINAL X-RAY NEGATIVE 5 BY 7 IN.

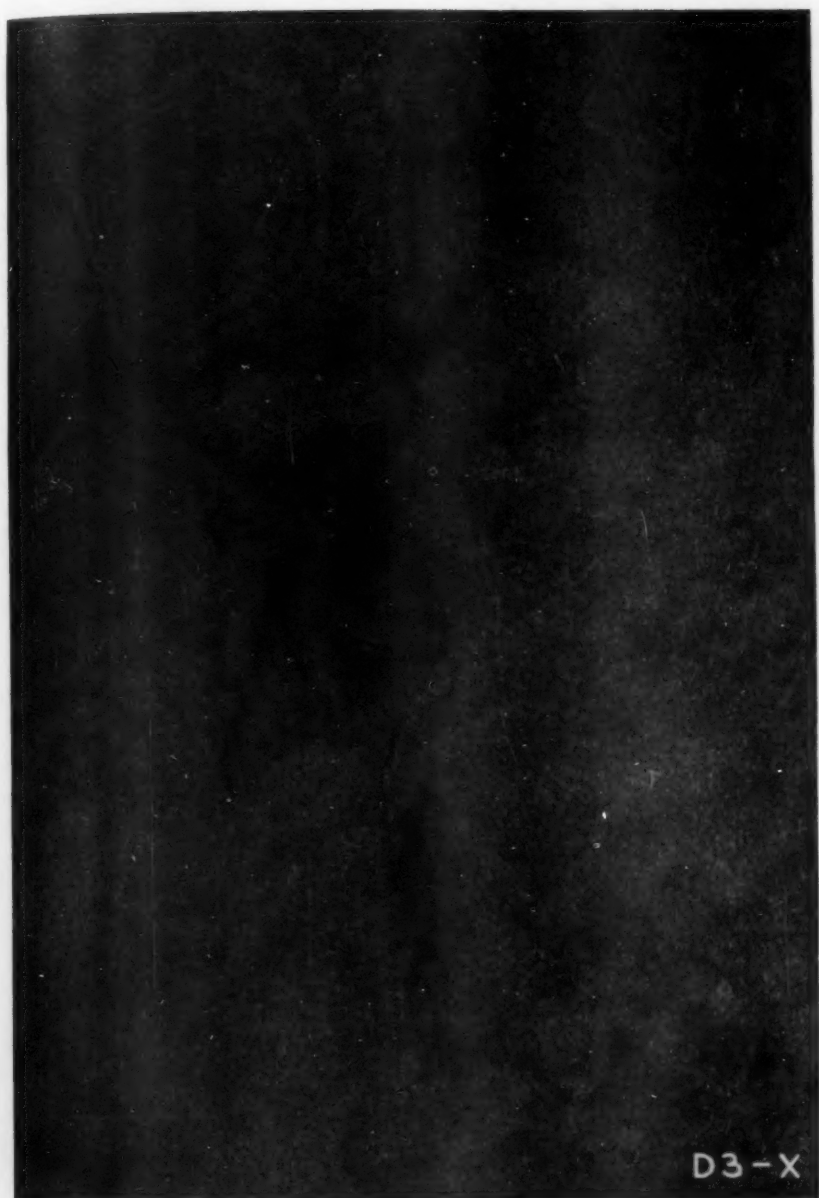


FIG. 4—HOT TEARS, UNACCEPTABLE IN ALL CLASSES OF CASTINGS. ORIGINAL X-RAY NEGATIVE 5 BY 7 IN.

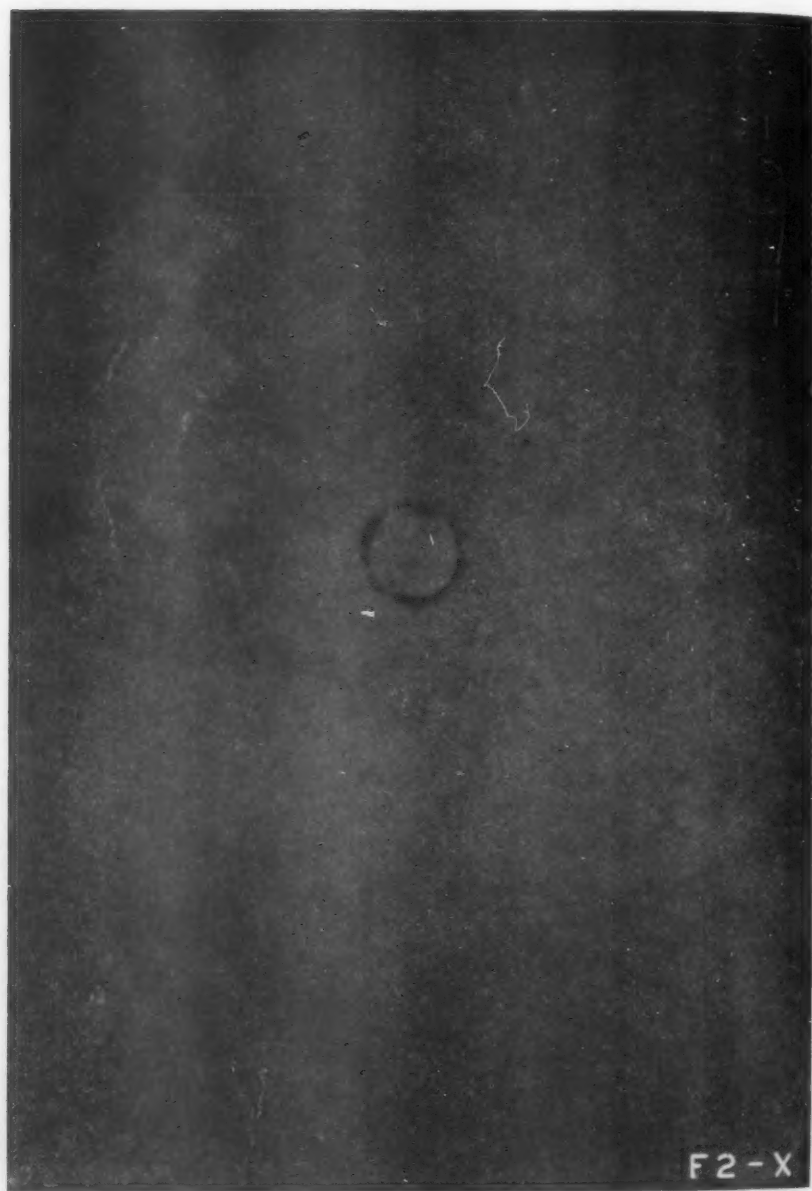


FIG. 5--UNFUSED CHAPLET, BORDERLINE ACCEPTABILITY IN CLASS 3 CASTINGS. ORIGINAL X-RAY NEGATIVE  
5 BY 7 IN

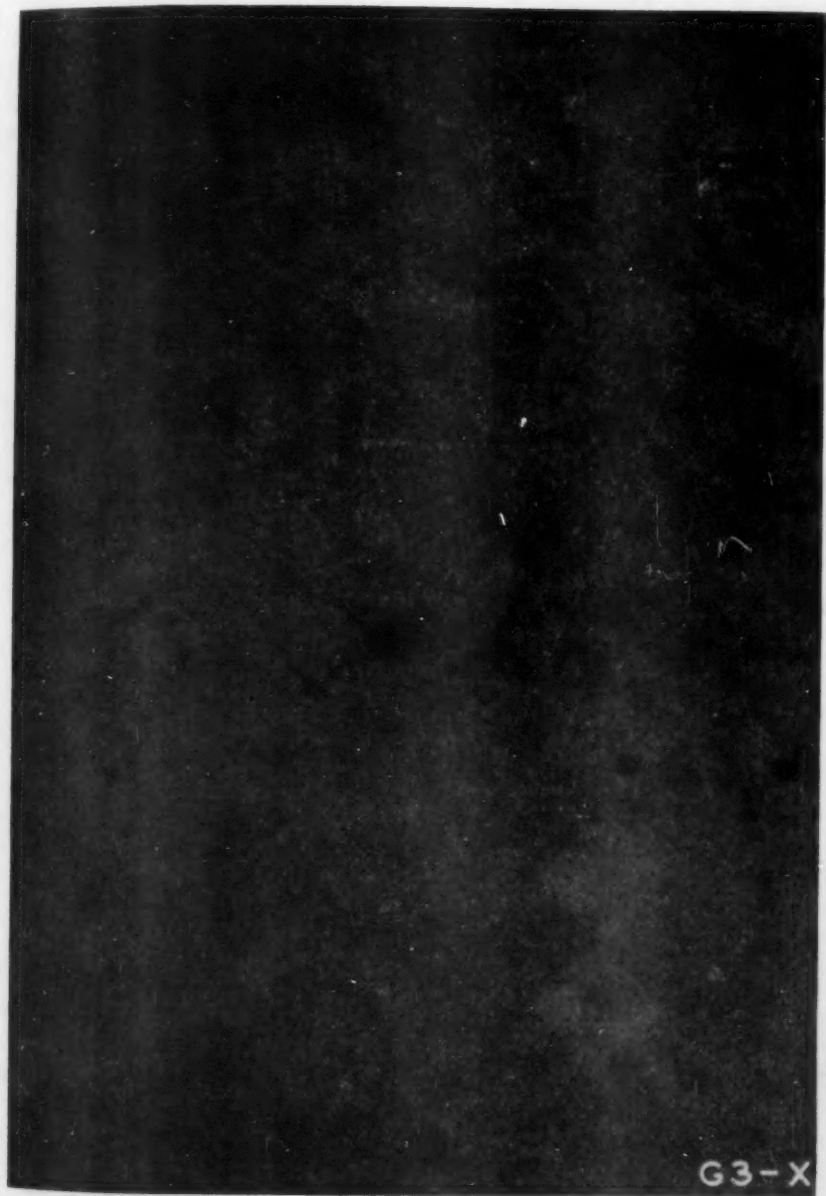


FIG. 6—UNFUSED CHILL, BORDERLINE ACCEPTABILITY IN CLASS 5 CASTINGS. ORIGINAL X-RAY NEGATIVE  
5 BY 7 IN.

21. In addition to the "*Radiographic Standards for Steel Castings*," the Bureau of Ships has issued a set of standards entitled "*Radiographic Standards of the Bureau of Ships for Class A-1 Welds*," dated October 1, 1940, which shows the extent of defects permitted in welds made in fired and unfired pressure vessels and high-pressure piping.

## Appendix I

### GENERAL SPECIFICATIONS FOR INSPECTION OF MATERIAL\*

#### APPENDIX II—METALS

#### PART F—RADIOGRAPHY

#### SECTION F-1, DEFINITIONS AND RADIOGRAPHIC REQUIREMENTS

##### I. GENERAL

This specification forms a part of all Navy Department specifications and Bureau of Ships specifications where radiographic examination is required in the inspection of material, insofar as the Bureau of Ships is concerned.

##### II. DEFINITIONS

- (a) *Radiography*—The use of radiant energy in the form of X-rays or gamma-rays for non-destructive examination of opaque objects, in order to produce graphical records on sensitized films which indicate the comparative soundness of the object being tested.
- (b) *Radiograph*—A shadow picture produced by passing X-rays or gamma-rays through an object and recording the variations in the intensity of the emergent rays on a suitable sensitized film.
- (c) *Exograph*—A radiograph produced by X-rays.
- (d) *Gamma-graph*—A radiograph produced by gamma-rays.
- (e) *X-rays*—A form of radiant energy resulting from the bombardment of a suitable target by electrons produced in a vacuum by the application of high voltages. X-rays have wave lengths between  $10^{-11}$  cm. and  $10^{-8}$  cm.
- (f) *Gamma-rays*—A form of radiant energy resulting from the atomic decomposition of radio-active matter. Gamma-rays have wave lengths of  $10^{-11}$  to  $10^{-8}$  cm.
- (g) *Cassette*—A lightproof container used for holding the radiographic films in position during the radiographic exposure.
- (h) *Intensifying screen*—A layer of material placed in contact with the film to increase the effect of the radiation, thus shortening the exposure or increasing the contrast, or both.

\*Issued by the Bureau of Ships, Navy Department, Washington, D. C., March 1, 1942, Preliminary Draft.

NOTE: Copies of this Specification may be obtained upon application to the Bureau of Ships, Navy Department, Washington, D. C. When requesting refer to Appendices by both title and number.



- (i) *Filter*—A layer of absorptive material which is placed in the beam of radiation for the purpose of absorbing rays of certain undesired wave lengths and thus control the quality of the radiograph.
- (j) *Bucky diaphragm*—A grid composed of small lead plates or sheets lying parallel to the emergent X-rays. This grid is oscillated during the exposure and serves to absorb secondary rays emergent from the object not in a direct line from the X-ray source thus preventing blurring of the image which would result if such scattered rays reached the film.
- (k) *Penetrameter (sensitivity gage)*—A strip of metal the radiographic density of which is the same as that of the metal being tested, of suitable thickness and provided with a combination of steps, holes or slots. When placed in the path of the rays, its image provides a check on the radiographic technique employed.
- (l) *Focus-film distance (abbreviated F.F.D.)*—The distance in inches between the focal spot of the X-ray tube or the radium capsule and the film.
- (m) *Halation*—The spread of the image in regions of intense exposure due to photochemical action in the film or intensifying screens or to fluorescent light scatter, but not to scattered radiographic rays.
- (n) *Undercut (edge halation)*—The excess blackening of the film within the image of any unblocked edge due to secondary radiation passing around, not through, the object.
- (o) *Fog*—A darkening of the film resulting from chemical action of the developer, aging, scattered secondary radiation, or exposure to visible light.

### III. GENERAL REQUIREMENTS

- (a) *Source of radiation*—Either gamma-rays or X-rays may be used (see note 1).
- (b) Accredited laboratories and process approval:
  - (1) Before any private laboratory will be permitted to perform radiographic examination for the Bureau of Ships using either X-ray or gamma-rays, a process approval test will be required.
  - (2) For qualification under the Bureau of Ships a set of radiographic test blocks shall be obtained through the Naval inspector. These blocks contain synthetic defects of known size and location and shall be radiographed in duplicate by the exhibitor using his regular technique in accordance with directions furnished with the blocks. After processing, the duplicate radiographs shall be forwarded to the bureau via the Material Laboratory, Navy Yard, New York, for interpretation.
- (c) *Films*—All films for use under this specification shall be in accordance with the latest issue of Navy Department Specification 18F1, Film, Radiographic, Industrial.

## (d) Intensifying screens:

- (1) Lead intensifying screens approximately 0.006 inch in thickness shall be used in the production of radiographs using gamma-rays. They may be used where desired in the production of X-ray radiographs where the use of industrial intensifying screens is either impracticable or unsuitable. When lead screens are used in the radiography of castings, duplicate films shall be exposed in the same cassette, the arrangement being as follows:

## Lead-film-lead-film-lead.

Care shall be taken that the lead is free from wrinkles and that it lies in actual contact with the film at all points. The use of paper or other material between the film and the lead will not be permitted.

- (2) Chemically coated screens shall ordinarily be used in the production of X-ray radiographs. Where their use is impracticable, such as in locations where it is necessary to bend the cassette, lead screens shall be used. Chemically coated screens shall not be used with the non-screen types of films. Lead screens are suitable, however, for use with this type of film. (See note 4.)
- (e) *Penetrameters*—All radiographic examinations shall be performed with a technique which will be capable of indicating the presence of defects having depths equal to 2 per cent of the thickness of the material being tested, and a width equal to 4 per cent of the thickness of the material. To determine the requisite sensitivity of the radiographic technique being employed, penetrameters made of material, the radiographic density of which is approximately the same as that of the material being radiographed, shall be used.
- (1) *Position of penetrameters*—In general, penetrameters shall be placed on the source side of the object being radiographed. All radiographs shall show the image of the penetrameter except in cases where a number of films are exposed at the same time, all conditions of exposure such as metal thicknesses and source to film distance being the same with all films, in which case only a single radiograph of the group will be required to show the penetrameter. In this case the control film shall be adequately referenced and shall accompany the other films of the same group submitted for interpretation.
  - (2) Where the thickness of the metal is not uniform but does not vary by more than  $\frac{1}{2}$  in. in section, whichever is the lesser, over the area covered by a single radiograph, one penetrameter shall be required, which shall be located at the point of the mean thickness.
  - (3) If the thickness of metal covered by a single radiograph varies by more than 50 per cent of the maximum thickness or by more than  $\frac{1}{2}$  in., whichever is the lesser, suitable penetrameters shall be placed at the thinnest and the thickest portion being radiographed.

- (4) For positioning of penetrameters in radiographing assembly welds see paragraph IV(b) 4.
- (5) *Penetrameter design*—Acceptable designs of penetrameters are indicated by Figs. 1 to 6, inclusive.
- (f) *Limiting distances*—During exposure the film shall be as close as practicable to the surface of the object being radiographed.
- (1) When using gamma-rays the focus-film distance for maximum registry of defects will depend upon the size of the radium capsule and the thickness of the metal being radiographed. Table 1 shows the shortest focus-film distance which shall be used in radiographing 1-in., 3-in. and 4-in. sections of steel with different size radium sources.

Table 1

## MINIMUM FOCUS-FILM DISTANCE FOR GAMMA-RAY RADIOGRAPHY

Source Mg.	Section Thickness		
	1	3	4
	Inches	Inches	Inches
25	6	9	15
100	8	10	17
250	10	12	20
500	14	16	23

- (2) When radiographing flat surfaces, the focus-film distance shall be not less than the largest linear dimension of the area being radiographed.
- (3) When using X-rays the focus-film distance shall be not less than seven times the thickness of the metal being radiographed and in general, the distance shall be not less than 36 inches. (See note 5).
- (g) All radiographs shall be free from processing or other film defects which would interfere with proper interpretation of the radiograph. When an apparent defect is indicated by any radiograph which, by comparison with the object being radiographed, is shown conclusively to be entirely on the surface, the area on the radiograph shall be encircled by the Naval inspector and identified as a surface imperfection by the letter "S" placed immediately adjacent to the encircled area. Great care shall be taken to ascertain that such markings are due entirely to surface markings and not partly due to underlying internal defects.
- (h) Identification markers shall be placed on the film side of the casting in such a manner that the images will appear on the radiograph. The location of these markers shall be accurately and permanently stamped or stenciled on the metal surface in order that the orientation of the radiograph may be established and the defects indicated on the negative accurately located in the object radiographed. Where such stamping or stenciling is impracticable the outline of the cassette may be painted on the object radiographed with sufficient permanence that it will be avail-

able as long as necessary in the repair of defects and the location of films for radiographing repairs.

- (i) When doubt exists concerning the interpretation of radiographic negatives, reradiographing may be required. (See note 6.)
- (j) A photograph, sketch or marked plan shall be submitted showing the exact location of all radiographs in such a manner that the location of any defect may be positively identified with respect to the object radiographed.
- (k) The necessity for repair of defects revealed by radiographic inspection or the acceptability of defects without repair shall be determined by comparing the radiographs with a set of radiographic standards applicable to the object radiographed.

#### IV. DETAIL REQUIREMENTS

- (a) Radiographic examination of castings:

- (1) Where radiographic examination of castings is required by the applicable specification or by the contract or order, radium, films and cassettes will be furnished by the bureau via the Naval inspector. Although the Government will be responsible for processing the films, it may be to the advantage of the contractor to furnish the radiographic accessories and processing facilities without cost to the Government, in order to expedite completion of the contract. When the radiographic examination is performed using X-ray machines belonging to the contractor, no charge shall be made to the Government for the use of such X-ray machines or the power consumed thereby. All phases of radiographic inspection shall be under the supervision of the Naval inspector who will interpret the radiographs or forward them to the bureau for action in accordance with applicable directives.
- (2) Radiographic examination shall be conducted on the first casting of a particular design in those locations indicated on a plan marked by the bureau.
  - (2)a Three copies of type B plans or contractor's working drawings shall be forwarded to the Bureau of Ships to be marked for radiographic examination. One of the marked plans will be retained by the bureau and 2 copies returned to the inspection activity. One of these plans shall be forwarded to the contractor who will incorporate the markings on the plans. The plans will be marked with symbols in accordance with General Specifications for Inspection of Material Appendix II, Metals, Part F, section F-2. These markings shall also be incorporated in the type D or other plans which are prepared for ship's use in order to keep a permanent record of the castings which have been radiographed. In lieu of incorporating the radiographic markings on the regular plans, where such markings may

obscure necessary details, a separate plan may be prepared showing the necessary design details and on which the markings may be incorporated. Such a plan should be positively identified with the plan on which the part is detailed.

- (2)b If the Naval inspector has reason to believe that harmful defects exist in parts other than at those locations marked for radiographic examination, he shall reject the casting. If the manufacturer wishes to salvage the casting the Naval inspector may request radiographic examination at the suspected areas in order to determine the presence and extent of the defects.
- (3) When a number of castings are to be made from the same pattern or design by the same foundry (port and starboard castings and right and left-hand castings are considered as the same design provided all details except opposite hand locations are the same), the amount of radiographic examination to be conducted on subsequent castings of the same design may be reduced as the Bureau of Ships or its authorized representative considers permissible after examination of the radiographs from the first casting, provided the same foundry technique is used in producing the subsequent castings.
  - (3)a If, at any time after the first casting is produced, the manufacturer elects to alter his foundry technique in order to eliminate defects revealed in the first or subsequent castings, the first casting submitted for inspection after such change shall be considered as a new "first casting" and shall be subjected to radiographic examination in accordance with the marked plans.
  - (3)b When the manufacturer has a number of orders for duplicate castings and employs the same foundry technique in their production these castings may be considered as subsequent castings, provided that not more than six months shall have elapsed between the completion of one order and the start of the succeeding order. Where more than six months have elapsed before starting the manufacture of a succeeding order, the first casting of the new order shall be radiographed in accordance with the marked plans.
  - (3)c Where a number of castings of the same design are produced by a standardized technique, the Naval inspector shall select at least one casting from each lot of twelve subsequent castings produced and shall subject the selected castings to radiographic inspection in accordance with marked plans.
  - (3)d All integrally cast bosses and all chaplets and internal chills shall be radiographed on all castings, even though the radiography is not indicated on the marked plan.
  - (3)e Radiographic examination shall be conducted on the heat

treated and, in most cases, on the rough machined casting. Where radiographic inspection after rough machining will unduly delay completion of the contract, such inspection may be made before machining provided that the surface of the casting is sufficiently smooth and the cross section is sufficiently close to that of the rough machined casting that no internal defects are obscured and the sensitivity is equal to 2 per cent of the rough machined dimensions.

(b) Radiographic inspection of welds.

- (1) All assembly and repair welds shall be radiographed when the material being welded is intended for service in an application class requiring radiographic inspection as defined in Subsection S1-4 of General Specifications for Machinery, or listed in the Navy Department and Bureau of Ships specifications, covering the particular class of material. (See note 7.)

- (1)a Welds in steel piping under classification P-1 of Subsection S1-4 of General Specifications for Machinery shall be radiographed when the inside diameter of the pipe is greater than 2 inches.

- (1)a(1) When radiographing welds in steel piping the inside diameter of which is  $2\frac{1}{2}$  in., 3 in. or  $3\frac{1}{2}$  in. only one exposure shall be required per weld, the cassette being placed flat against the outside surface of the pipe, and the source located opposite in such a manner that the rays pass through the pipe at an angle not less than 15 degrees to a plane passing through the weld.

- (1)a(2) When radiographing welds in piping the inside diameter of which is 4 in. or greater, the cassettes should be placed inside the pipe where this is practicable, in order that the rays shall be required to penetrate only one thickness of metal. At least six exposures should be made in radiographing the full extent of the weld.

- (1)a(3) In locations where it is impracticable to place the cassette inside the pipe, the inspection may be conducted as described in paragraph (1)a(1), except that at least four exposures shall be required to radiograph the full extent of the weld.

- (1)a(4) When the diameter of the pipe or cylindrical casting is such that the source of radiation may be located inside without reducing the focus-film distance below the requirements of paragraph III(f) the cassettes may be grouped around the outer surface of the cylinder. With such an arrangement it may be pos-



sible to radiograph a complete circumferential weld with one exposure.

- (2) The surface of all welds shall be cleaned and if necessary ground sufficiently to remove all surface imperfections which may obscure internal defects or which may be identified as such.
- (3) Identification markers and penetrameters shall be placed within  $\frac{1}{4}$  in. of the toe of the weld as illustrated by Fig. 7 in order to indicate the location and extent of the weld on the radiograph. When the dimension of the film in the direction of the weld is not greater than 6 in., only one penetrameter will be required to be visible on each film; above this dimension, two penetrameters shall be used. At least two identification markers shall be visible on each radiograph of assembly welds, and the distance between any two adjacent markers shall not be more than 6 in.
- (4) In general, the penetrameter shall be placed on the source side of the actual area being tested.
  - (4)a When a single exposure is made with source and film, both outside the pipe in order to radiograph a complete weld, the penetrameter shall be placed on the outside of the pipe nearest the source of the rays.
  - (4)b When more than one exposure is made with the film and source both outside the pipe, the penetrameter shall be located inside the pipe adjacent to that part of the weld which the radiograph represents.
  - (4)c When a number of exposures are to be made with the source outside the pipe and the film inside, the penetrameter shall be placed on the outside of the pipe nearest the source of the rays.
  - (4)d When radiographing an assembly weld with the source located inside the object under test the penetrameter shall be located on the inside surface.
  - (4)e In cases where placement of the penetrameter on the source side is impracticable without cutting a hole in the wall, the penetrameter may be placed on the film side of the object being tested under the following conditions: A test radiograph shall be made duplicating all the conditions under which the actual inspection shall be conducted. Similar penetrameters shall be placed on the source and the film side. If the penetrameter on the source side indicates the required sensitivity, the image of the penetrameter on the film side shall be used as a standard for interpreting the sensitivity obtained in the actual inspection radiographs where the penetrameters are placed on the film side.
- (c) Radiographic inspection of materials other than castings or welds shall be conducted as directed by the Bureau of Ships.

(d) Submission and disposition of radiographs.

- (1) The duplicate radiographs of the first casting shall be forwarded to the Bureau of Ships or its authorized representative for interpretation, action and decision concerning the locations to be radiographed on subsequent castings. The following information shall be furnished with each lot of radiographs representing each casting:

Ship or group of ships for which casting is furnished.

Name of casting and its location (port, starboard, forward, aft).

Name of contractor and order number.

Bureau plan number on which the part is detailed.

Material.

Identifying symbol. (See note 8.)

Location sketch, photograph, or plan.

- (2) Submission, storage and disposition of radiographs shall be in accordance with instructions issued by the Bureau of Ships.

#### NOTES

1. The following information is given as an aid in selecting the proper equipment for conducting radiographic inspection.

1a. Gamma-rays are especially useful where portability is a factor, the radium being capable of easy transportation from place to place, thus permitting radiographic inspection in locations where the use of an X-ray machine would be impossible. Gamma-rays are suitable for all thicknesses of steel in the range of  $\frac{1}{2}$  in. to 6 in. Above this thickness, the necessary exposure time becomes so long that the use of gamma-rays is impracticable in most cases.

1b. X-rays produced by 140 KV equipment are suitable for radiographing steel up to approximately 1.25 in. in thickness, their greatest use being in the inspection of piping welds and other thin, uniform wall material. The sensitivity and detail obtained with such low voltage X-rays are usually superior to those which can be obtained by gamma-rays.

1c. X-rays produced by 200 to 220 KV are suitable for uniform steel thickness up to approximately 3 in. with a sensitivity about equal to that obtained with gamma-rays in 3-in. sections but superior to gamma-rays in thinner sections. A Bucky diaphragm should be used when radiographing steel sections greater than  $2\frac{1}{2}$  in.

1d. X-rays produced by 400 to 500 KV are suitable for uniform steel thickness up to approximately  $4\frac{1}{2}$  in., producing a sensitivity in such sections approximately equal to that obtained with gamma-rays. A Bucky diaphragm should be used when radiographing sections above 3 in.

1e. X-rays produced by a 1000 KV source have wave lengths approaching those from radium and are suitable for steel thicknesses as high as 8 in.

2. The exposure time for either gamma-rays or X-rays is a function of the density of the material being radiographed, the required exposure time increasing as the density of the material increases.

3. In using X-rays of 500 KV or less intensity, on nonuniform thicknesses of metal, it may be necessary to take separate exposures for the different thicknesses, or block up the thinner sections with copper powder or other suitable material in order to increase the radiographic density of these thinner sections to that of the heavier sections. It is also necessary to block holes and edges of the material in order to prevent halation and undercutting. It is usually necessary to back up the cassette with lead when using X-rays from potentials of 500 KV or less. When using gamma-rays or 1000 KV X-rays this blocking of the thinner sections and edges is usually not necessary. Gamma-rays and 1000 KV X-rays are especially useful in radiographing nonuniform sections where blocking is impracticable.

4. When duplicate X-ray negatives are desired, they may be obtained by using lead screens as for gamma-ray radiography with little or no increase in the tube voltage. By the use of a flexible double-faced chemically coated screen not over 0.05 in. in thickness placed between the two films, duplicate exographs may be obtained using the regular industrial cassettes fitted with chemically coated screens with approximately 5 per cent increase in the exposure time or the voltage.

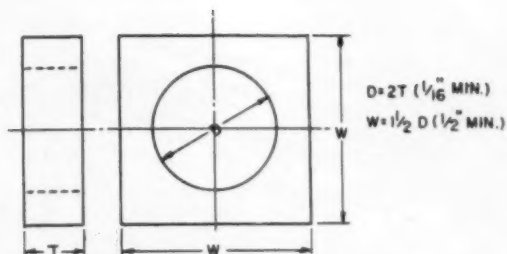
5. When using 140 KV or lower voltage X-ray equipment, it may be possible to obtain satisfactory results with a 24 in. or even shorter focus-film distance. The minimum focus-film distance with 1000 KV X-rays is usually 72 in. However, when very low currents are being used with 1000 KV equipment, the size of the focal may be reduced which will permit shorter focus-film distances.

6. When making a second radiograph it will often be advantageous to alter the position of the source and film in order that the defect may be registered from a different angle. This should aid, not only in the correct interpretation of the defect, but also in determining its exact location in the object being radiographed. The use of stereoscopic radiography is recommended wherever practicable. By this method, two radiographs are made of the same defect, the only difference in the two exposures being that the focal spot is displaced a distance of approximately one inch for each 10 in. of focus-film distance. When the two radiographs are viewed stereoscopically, it is possible to visualize the third dimension, and thus determine the shape of the defect and its location with respect to the surfaces of the object being radiographed.

7. After a major defect has been removed the area should be radiographed in order to determine whether the removal of the defect is complete before welding. This radiograph will often obviate the necessity for radiographing prior to the removal of a defect revealed by surface inspection or other means.

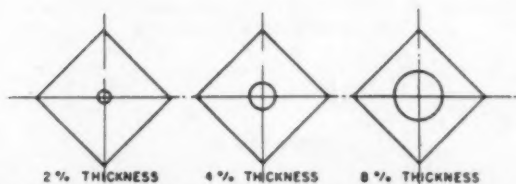
8. The identifying symbol should be decided by the Naval inspector and should be transferred to the casting in such a manner that it shall form a means of positive identification when the casting is installed.





INDIVIDUAL PENETRATOR PIECES. SEE FIGURES 4 AND 5 FOR ACCEPTABLE METHODS OF USING THESE PIECES.

FIGURE 3



INDIVIDUAL PENETRATOR PIECES TO BE SELECTED REPRESENTING 2%, 4% AND 8% OF SECTION THICKNESS AND PLACED ON SOURCE SIDE OF AREA BEING TESTED AND HELD IN PLACE WITH ADHESIVE TAPE IF NECESSARY. THE CORNER TO CORNER ARRANGEMENT AS ILLUSTRATED IS PREFERABLE TO A PARALLEL SIDE ARRANGEMENT.

FIGURE 4

NOTE THICKNESS OF PENETRATOR PIECES SAME AS SHOWN IN FIG 1. OTHER DIMENSIONS SAME AS SHOWN IN FIG 3

ADHESIVE TAPE TO BE FOLDED LENGTHWISE OVER PENETRATOR PIECES (PIECES TO BE SPACED APPROXIMATELY 1/8\"/>

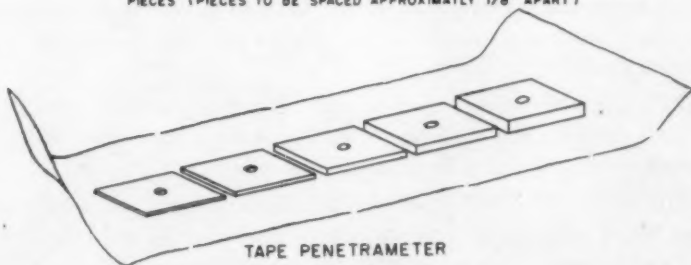
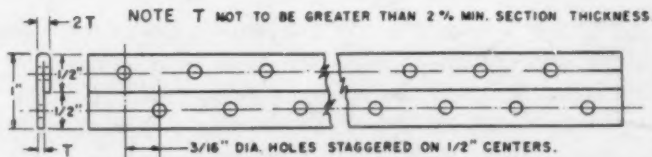
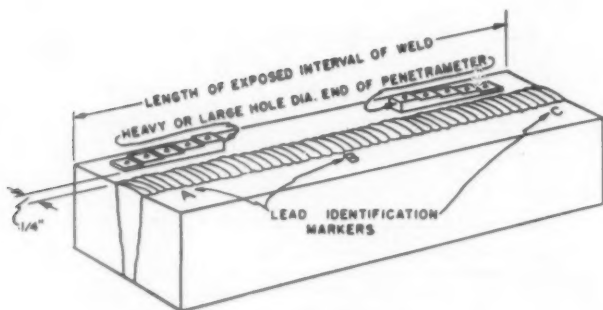


FIG 5



DOUBLE THICKNESS STRIP PENETRATOR

FIG. 6



POSITIONING OF PENETRATORS AND IDENTIFICATION MARKERS  
FOR EXAMINATION OF WELDS

FIG 7

## Appendix II

### GENERAL SPECIFICATIONS FOR INSPECTION OF MATERIAL\*

#### APPENDIX II—METALS

#### PART F—RADIOGRAPHY

#### SECTION F-2, RADIOGRAPHIC SYMBOLS

##### Sub-Section 1. *Applicable Specifications.*

1a. This appendix forms a part of the Navy Department General Specifications for Inspection of Material, of the issue in effect on date of invitation for bids, and bidders and contractors should provide themselves with the necessary copies.

1b. This appendix covers methods of indicating the placement of radiographic film cassettes and the radium or X-ray focal spot when radiographic examination is specified as a method of inspection.

1c. The following Navy Department Specification is applicable to work performed in accordance with the directions given herein and contractors and bidders should provide themselves with the necessary copies:

General Specifications for Inspection of Material:

Appendix II—Metals, Part F—Radiography;

Section F-1—Definitions and Radiographic Requirements.

1d. The following Bureau of Ships Standards are also applicable to work performed in accordance with the directions given herein: (see note 7)

Radiographic Standards for Steel Castings, edition of July 1, 1942.

Radiographic Standards for Class A1 Welds, edition of Oct. 1, 1940.

\*Navy Department, Washington, D. C., 1 August 1942, Preliminary Draft (Superseding edition of December 1939).



Sub-Section 2. *Detail Requirements.*

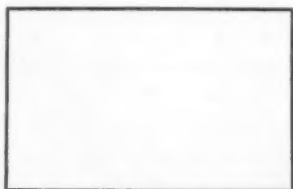
Plans which indicate the location of radiographic film cassettes and of radium or X-ray focal spot shall use radiographic symbols as set forth hereinafter.

2a. *Film location symbols.*

2a(1). Where the film is perpendicular to the plane of the plan, it shall be indicated by a straight line, thus:



2a(2). Where the film is paralld to the plane of the plan, it shall be indicated thus:



2a(3). Where the film is to be placed at an angle to the plane of the plan and a sectional symbol cannot be used, it shall be indicated by a rectangle or parallelogram.

2a(4). Where a continuous section is to be radiographed throughout its complete extent, the placement of films shall be represented where practicable on a sectional or other view by a single symbol, thus:



2a(5). Where the exact location of films cannot be indicated by any of the above symbols, the areas or sections to be radiographed shall be indicated thus:

2b. *Radium or X-ray focal spot symbols (see note 2)*

2b(1). The location of the radium capsule or X-ray focal spot shall be indicated thus:



2b(2). Where the use of the above symbol is impracticable, arrows pointing to the film and indicating the direction of the rays shall be used thus:



2b(2)a. Where the actual focus-film distance is indicated, it shall be shown thus:



—the number indicating the focus-film distance in inches.

2b(2)b. Where the distance indicated is the minimum to be used but this distance may be increased (see note 2), it shall be indicated thus:



2b(2)c. When the source is to be located at the centerline of the part being radiographed, it shall be indicated thus:

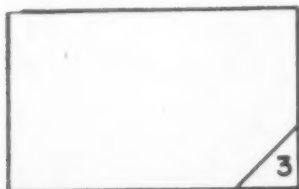


2c. *Casting Classification Symbols:* (see Radiographic Standards)

2c(1). Where the casting classification is indicated in connection with film symbols, it shall be shown thus:



or thus:



or thus:



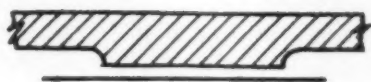
the number indicating the casting classification for the application of the Radiographic Standards, (see note 3).

### Sub-Section 3. *Explanations.*

3a. All radiographic symbols showing areas to be radiographed, location of films, and location of radium capsule, or X-ray focal spot shall be placed on the plan in a color or marking which will easily distinguish them from the construction and dimension lines.

### 3b. *Film Locations.*

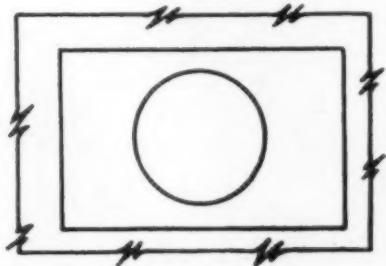
3b(1). Location of radiographic films shall be indicated by a straight line, thus:



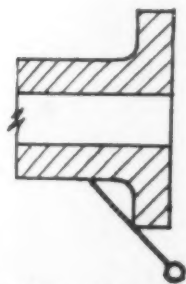
or a curved line, thus:



or a rectangle, thus:

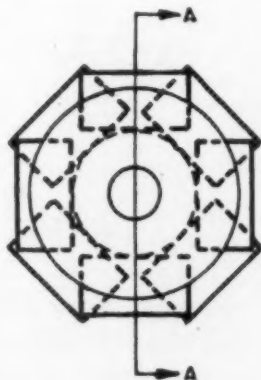


3b(2). When any continuous section is to be radiographed throughout its complete extent, it may be represented as a sectional or other view by a single symbol, thus:

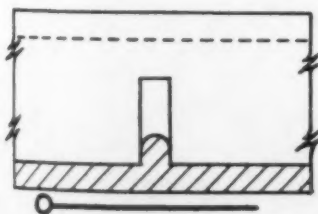


SECTION A-A

which indicates  
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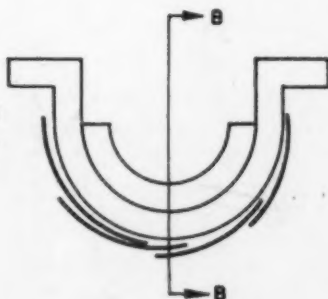


or thus:

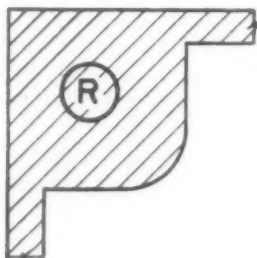


SECTION B-B

which indicates  
this arrange-  
ment of  
films

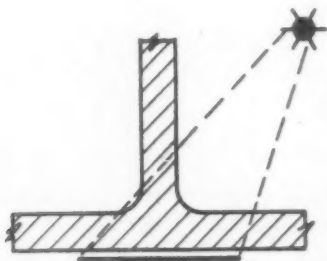


3b(3). When exact location of film cannot be shown by ordinary symbols, the exact film and radium locations shall be left to the judgment of the inspector and the area or section to be radiographed shall be indicated thus:

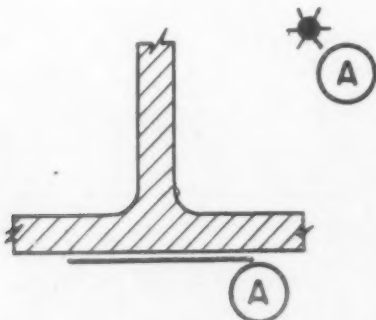


3c. *Radium or X-ray focal spot locations.*

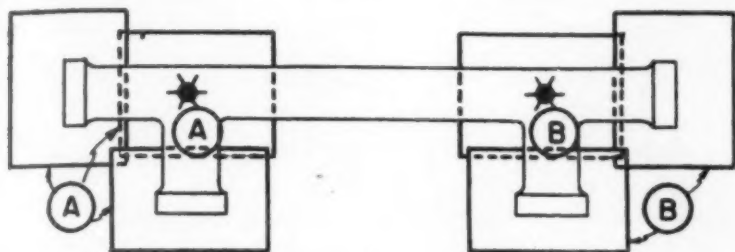
3c(1). When it is desired to show the location of the radium capsule in respect to the film, it shall be indicated thus:



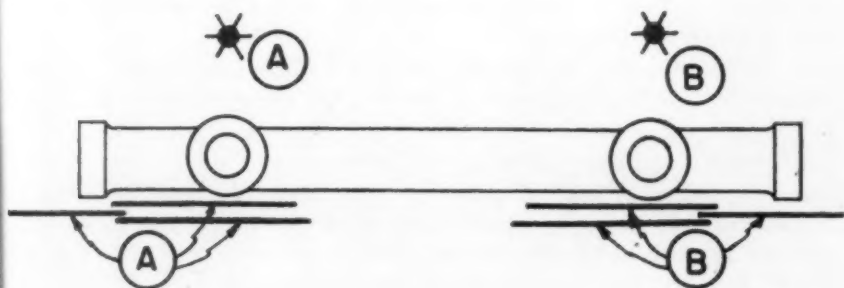
3c(2). If the dotted lines obscure dimensions or other details of the drawing, it shall be indicated thus: (The same letters are to indicate the film and radium capsule involved in the same exposure or set-up.)



3c(3)a. If two or more film locations are to be exposed, the location of the radium and films may be indicated thus:



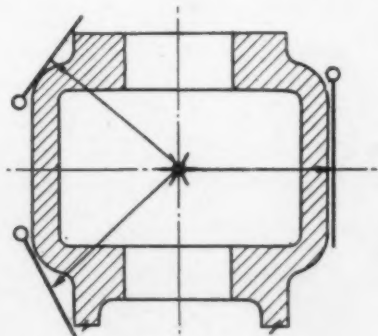
which in a side view would appear thus:



The same letters are to indicate the films and radium capsule involved in a single exposure or set-up such as:

Films labeled A should be exposed with radium at location A, those labeled B should be exposed with radium at location B. (Positions A and B to be radiographed by separate exposures.)

3c(3)b. The film and radium locations may also be indicated in a multiple exposure, thus:



Sub-Section 4. *Notes.*

1. Radiographic Standards are not available for general distribution. Contractors holding Bureau of Ships contracts in which radiographic inspection is specified may obtain copies of the standards upon application to the Bureau. Bidders and potential contractors may examine copies of the standards at the following offices:

Inspectors of Naval Material  
Inspectors of Machinery, U.S.N.  
Supervisors of Shipbuilding, U.S.N.  
Commandants, Navy Yards.

2. It may not be necessary to indicate the position of the source of the rays in all cases, as many exposures may be made with different focus-film distances, as determined by the time available such as set-ups using overnight exposures. Where a definite focus-film distance is necessary, however, it should always be indicated.

3. When a part to be radiographed is in a single classification, this classification may be stated adjacent to the detail of the part on the plan in lieu of indicating it on each symbol. Where all parts on a plan have the same classification, this classification may be indicated by a note on the plan. In cases where a single part belongs to two or more casting classifications, the separate sections may be indicated where practicable by lines drawn across the part and the correct classification indicated by a suitable note in each section.

4. Copies of Navy Department specifications may be obtained upon application to the Bureau of Supplies and Accounts, Navy Department, Washington, D. C., except that Naval activities should make application to the Commandant, Navy Yard, New York, N. Y. When requesting, refer to specifications by both title and number.

5. Copies of this specification may be obtained upon application to the Bureau of Ships or the Bureau of Supplies and Accounts, Navy Department, Washington, D. C. When requesting, refer to specification by both title and number.

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## X-ray Micrography as a Tool for Foundry Control

BY LESLIE W. BALL\*, BURBANK, CALIF.

### Abstract

*This paper briefly traces the use of X-ray micrography and shows that with the proper equipment and technique the procedure can be simplified. The paper shows that microcavities can be studied in sufficient detail to enable their proper diagnosis and correction. The paper also shows that an identification library of radiographs together with corresponding micrographs can be provided to assist X-ray interpreters in making decisions regarding castings.*

### INTRODUCTION

1. In good foundry practice it is usual to analyze sample castings and then to make adjustments in some of the production conditions. Any method of casting analysis which tells the foundrymen how the quality of his product can be improved, merits the term "A Tool in Foundry Control."
2. In this respect, ordinary radiography has been a tool in foundry control for many years. However, with some types of defects the information that it provided has been insufficient to show what sort of production adjustments were needed.
3. These ordinary X-ray pictures, as we have known them for the past decade, have been of the same size as the casting. They have been examined visually without any magnification. When occasionally radiographs were examined with, say, a 10-power reading glass, no advantage was achieved.
4. The uselessness of magnification was due to two factors. First, the emulsion on X-ray films was so coarse grained that it could not resolve fine detail. Second, in general practice X-ray pictures were made with a complete casting, some of whose sections were not in contact with the film. This meant that very fine detail could produce only a blurred image.
5. In recent years, both of these factors have been overcome. It is now possible to obtain much valuable information by examining suitable radiographs with a microscope at magnifications of from 2 to 200 diameters.
6. The term "X-ray micrography" should be applied to any X-ray picture in which viewing by a microscope or microphotography is used to bring out metallurgical information.

\*Triplett & Barton, Inc.

NOTE: This paper was presented at an Aluminum and Magnesium Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 25, 1944.

7. Most of the published papers on X-ray micrography have discussed rather refined and laborious procedures. They have described the use of special X-ray tubes and other complexities. Our experience has led us to recommend a very much simpler type of X-ray micrography for foundry investigations. This simple procedure is entirely satisfactory for indicating the cause and the cure for many types of casting defects. It also has been of great value as a method for establishing quality standards for different types of casting service.

#### TECHNIQUE

8. Historically, the first successful applications of X-ray micrography were in the study of biological subjects, such as the anatomy of insects. For this purpose, X-ray tubes operated at 5 to 10 kv. were found to be suitable. When the same equipment was used for examining metals, it required the preparation of slices of metal as thin as 0.0005 in. The preparation of these extremely thin slices was tedious. We have given a great deal of attention to preparing slices of metal and, in particular, we have exploited the metallographic cut-off wheel for this purpose.

9. Fortunately, our experience has shown that specimens of from 0.005 to 0.050-in. thick are most suitable in the investigation of foundry problems. Specimens of this thickness can be cut from any part of a casting, in a matter of minutes, by use of a suitable cut-off wheel.

10. It is our practice to clamp small castings in a specially designed vise, or to remove small sections from large castings with a band saw and then to mount these sections in the special vise. This vise must be extremely rigid and capable of being moved parallel to the axis of the cut-off wheel.

11. Figure 1 shows the preparation of slices from a small casting. Figure 2 shows how accurately and uniformly a definite slice thickness can be cut. Figure 3 shows two slices from another casting mounted on an X-ray film holder. For most problems it is satisfactory to place the slices on top of the opaque paper, but in a few cases, the slices are attached directly to the X-ray film or plate inside the holder.

12. Figure 4 shows an unmagnified radiograph of a slice from a magnesium sand casting. The dark area corresponds to defective metal, but the nature of the defect is not obvious. Figure 5 shows a small region of the same radiograph magnified 50 times. The detail seen on this illustration is similar to that obtained by placing the film under a microscope and viewing it with 50 diameters magnification.

13. The type of picture shown in Figs. 4 and 5 is made by X-raying a slice of metal exactly as it comes from the cut-off wheel. There is no other preparation of any kind. Only one tungsten or molybdenum target X-ray tube is required. It should have some type of thin window and should be operated at 20 to 50 kv. The exposures times are in the range of from 10 sec.

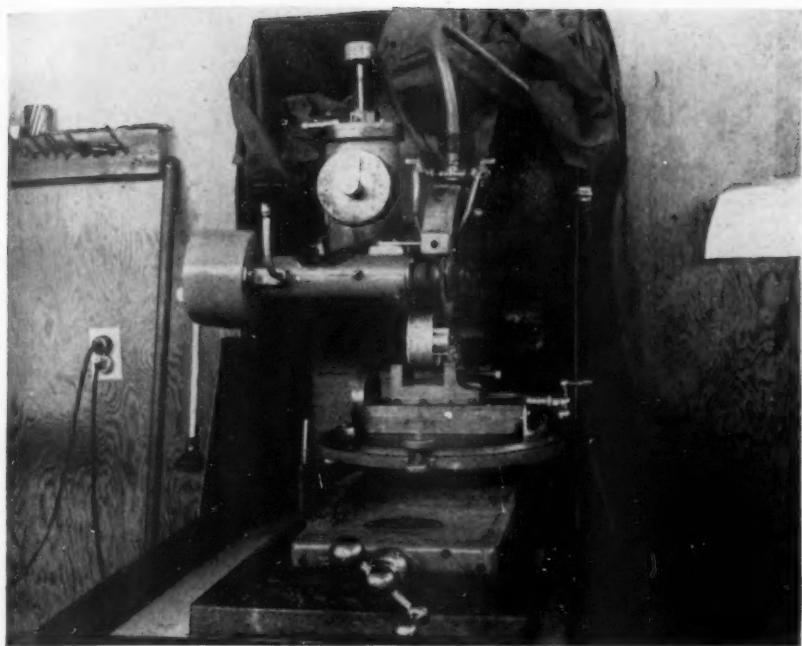


FIG. 1—HIGH SPEED CUT-OFF WHEEL ARRANGED FOR SLICING A SMALL CASTING. NOTE THAT VISE CAN BE MOVED PARALLEL TO THE AXIS OF THE WHEEL.

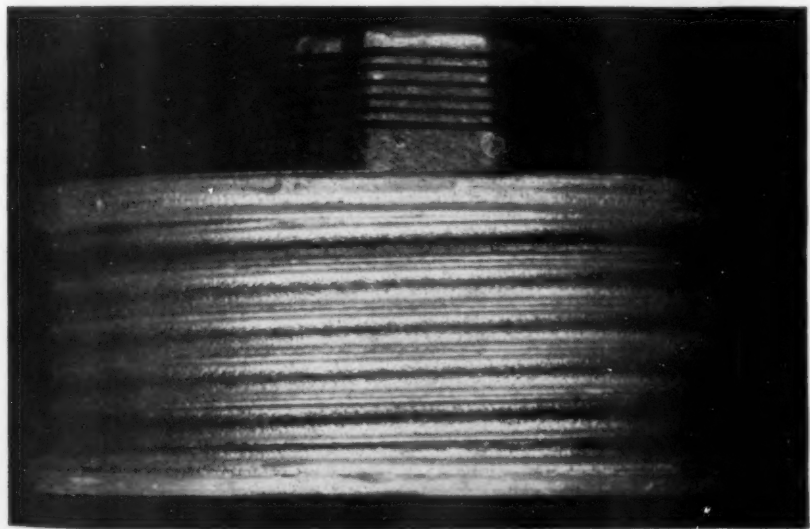


FIG. 2—SIX CUTS CAN BE SEEN IN THE HUE OF THIS SMALL PULLEY CASTING. THEY PROVIDE FIVE SLICES FOR X-RAY MICROGRAPHY.

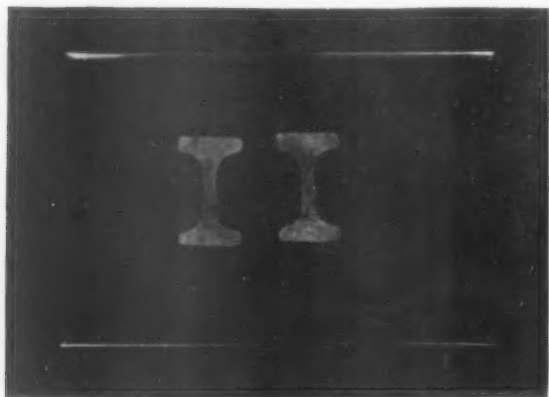


FIG. 3—FILM HOLDER WITH TWO SLICES OF METAL MOUNTED OUTSIDE OF THE BLACK PAPER.

to 10 min. Because the speed of the finest-grain plate is 1000 times less than that of ordinary X-ray film, it is very desirable to have available three types of film or plate. The first type should have the high speed and fine grain of the best commercially available double emulsion X-ray films. The second type should have the moderate speed and the much finer grain obtained in spectroscopic plates. The third type should be one of the extremely fine-grained plates used for making optical graticules. The best pictures always will be obtained on the finest grained plate. For practical purposes, magnifications of from 1 to 10 can be made from the X-ray film; magnifications of from 5 to 50 from the spectroscopic plate, and magnifications of from 25 to 200 from the special graticule plate.



FIG. 4—UNMAGNIFIED RADIOGRAPH OF A SLICE OF A MAGNESIUM CASTING SHOWING MICROSHRINKAGE.

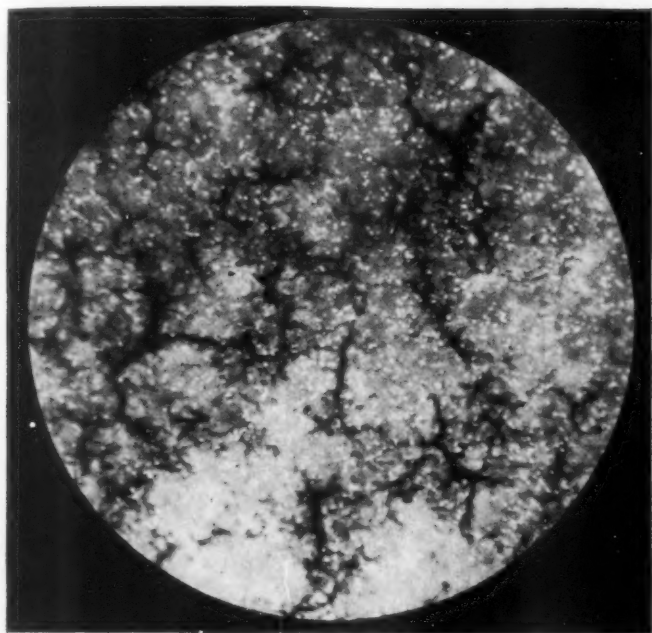


FIG. 5—X-RAY MICROGRAPH OF A SMALL AREA OF THE SAMPLE SHOWN IN FIG. 4. THE DARK NETWORK CORRESPONDS TO GRAIN BOUNDARY SHRINKAGE CAVITIES AND THE WHITE DOTS TO SEGREGATION OF A HEAVY METAL, PROBABLY MANGANESE. MAGNIFICATION, 50X.

#### APPLICATIONS

14. Now let us consider three specific applications of X-ray micrography to the analysis of castings. The most important of these is the study of microcavities. These microcavities are too small and too dispersed to be studied in detail by ordinary radiographs or by fracture tests, but their presence does affect the serviceability of a casting.

##### *Microcavities*

15. Figure 6 shows the simplest type of microcavity. It is the well-known gas porosity in aluminum castings. In this case, the individual cavities are spherical. The exact type of defect shown here does not have much effect on the strength of the casting, but there are other similar defects which do have a very marked effect on the casting strength.

16. Figures 7, 8 and 9 show some of these other types of microcavity. With good X-ray technique, the presence of microcavities is revealed on ordinary radiographs. In the case of aircraft and other high quality castings, microcavities may lead to rejection. Some of the larger types also show on smoothly machined surfaces. This, also, may lead to rejection. In either case, X-ray micrography can provide the detail necessary for the recognition of the cause of the microcavities and for their elimination by adjustment of

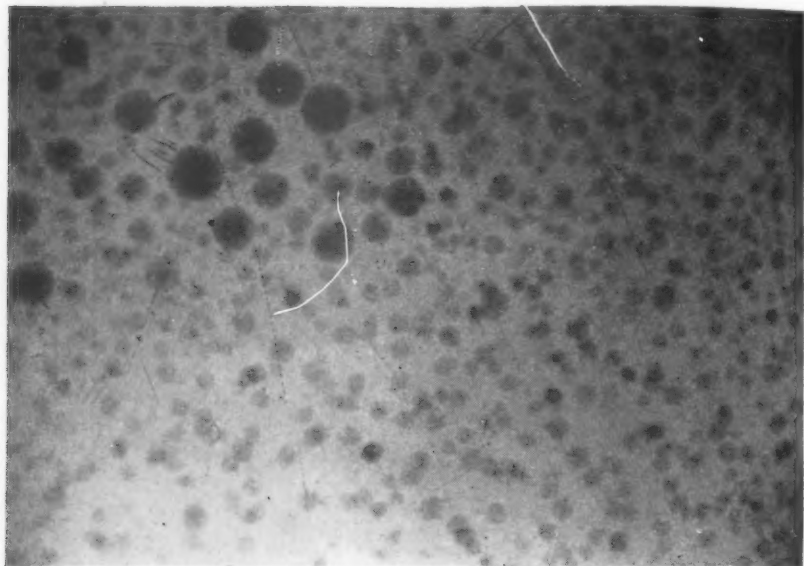


FIG. 6—GAS POROSITY IN AN ALUMINUM CASTING. MAGNIFICATION, 10X.

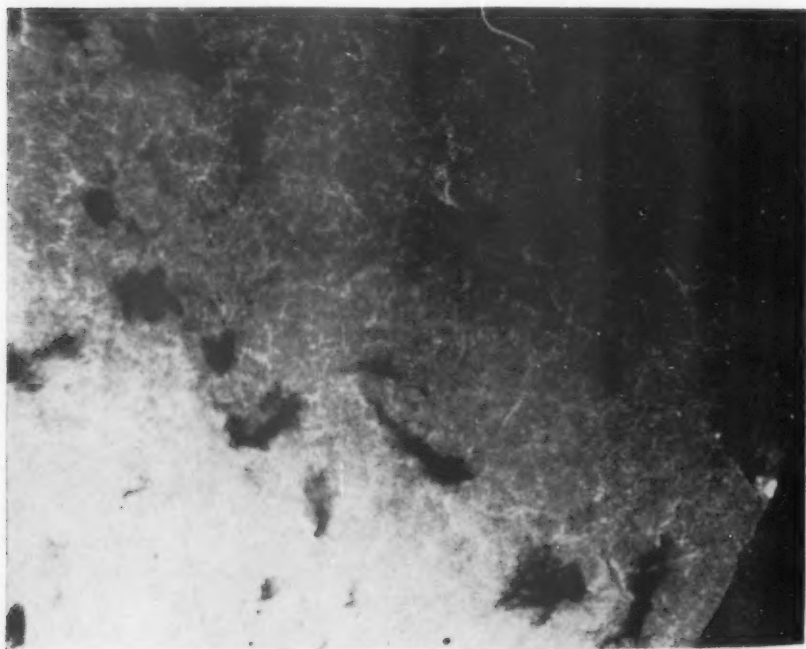


FIG. 7—GAS POROSITY MODIFIED BY SHRINKAGE. MAGNIFICATION, 10X.



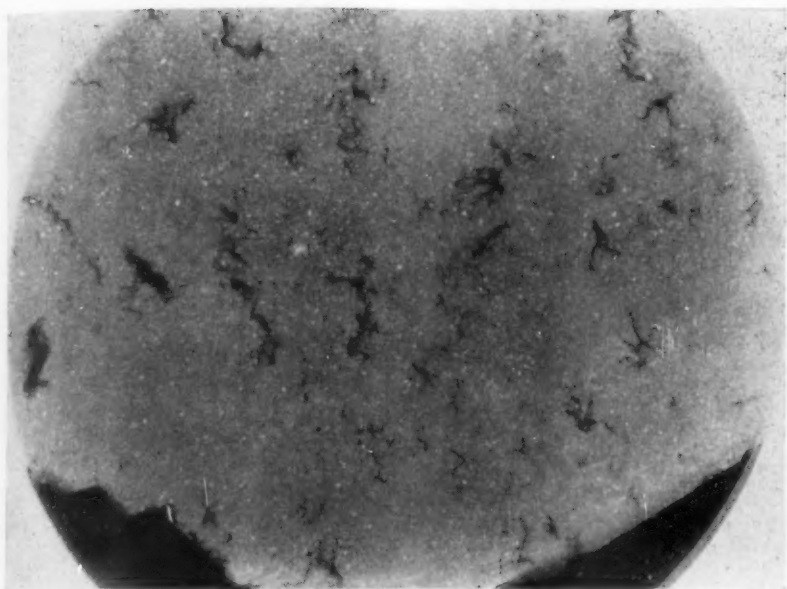


FIG. 8—SHRINK POROSITY IN AN ALUMINUM CASTING. MAGNIFICATION, 30X.

the foundry practice. The foundry factors concerned are: contamination of the melt by gases, shrinkage forces acting on the plastic metal, too slow a rate of cooling and the presence of scattered points of weakness due to finely dispersed oxides, etc.

#### *Segregation*

17. The second important application of X-ray micrography is the study of segregation in certain alloys and, particularly, in the copper-aluminum alloys. Figure 10 shows segregation in the corner of a box-shape casting. Figure 11 shows an enlargement of a radiograph of this type of defect. It is

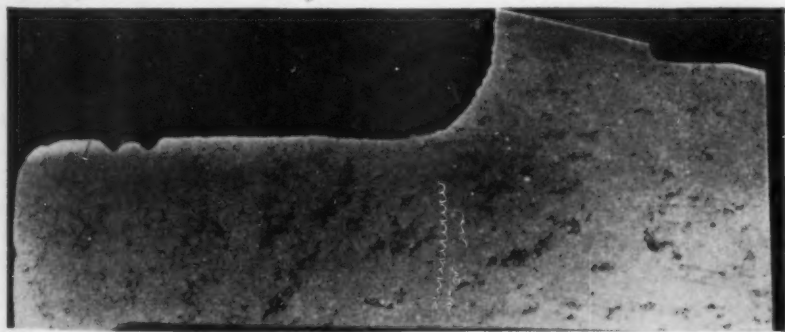


FIG. 9—SHRINK POROSITY IN A 90 PER CENT ALUMINUM-10 PER CENT MAGNESIUM CASTING. MAGNIFICATION, 4X.

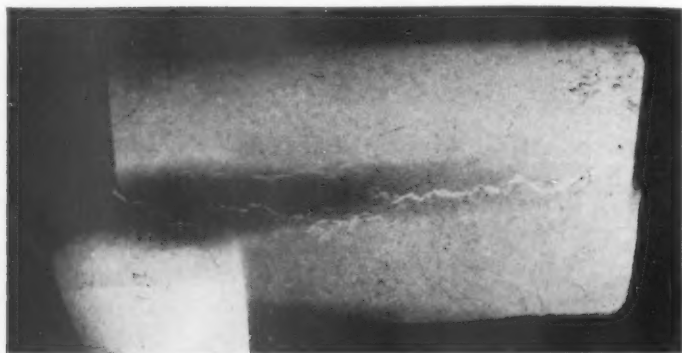


FIG. 10—STRESS SEGREGATION IN A 96 PER CENT ALUMINUM-4 PER CENT COPPER ALLOY. MAGNIFICATION, 2X.

obvious that the line of segregation is produced by the low-melting-point constituent flowing through the grain boundaries and filling up an incipient tear. This defect can be due to too high core strength.

18. Figure 12 shows a section from a leaded bronze bar. In this case, the dark copper segregation and the light lead segregation represents good metal. Figure 13 shows an enlargement of a radiograph of a similar alloy.

#### *Defect Identification*

19. The third important application of X-ray micrography is as a method of identifying defects seen on ordinary industrial radiography. X-ray inter-

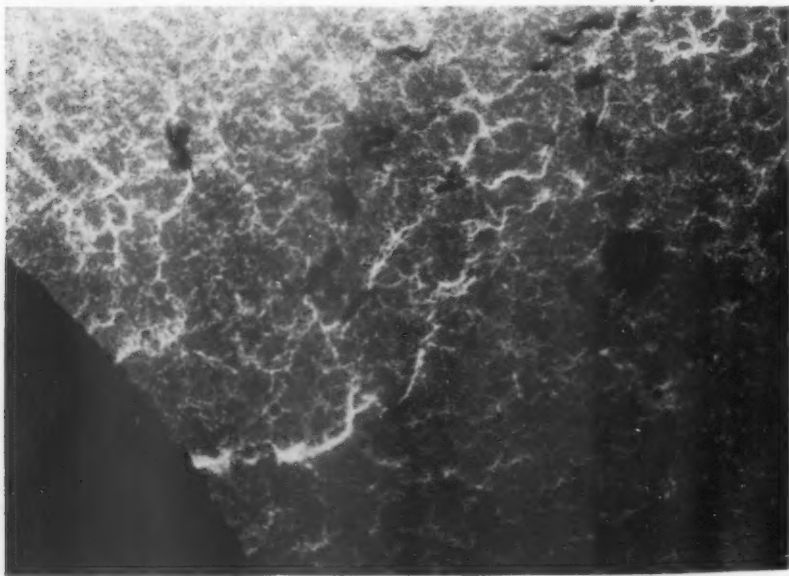


FIG. 11—STRESS SEGREGATION. MAGNIFICATION, 30X.



FIG. 12—X-RAY MICROGRAPH OF A SECTION OF A LEADED BRONZE BEARING ALLOY BAR. THE WHITE AREA CORRESPONDS TO LEAD, THE GRAY AREA TO COPPER AND THE BLACK AREA TO A SHRINKAGE CAVITY. ABOUT 30 GRAINS CAN BE DISTINGUISHED. MAGNIFICATION, 4X.

preters have to make decisions involving many thousands of dollars worth of castings. We believe that their training for this task should be very thorough. In our laboratories, one part of this training is provided by an identification library of radiographs together with corresponding X-ray micrographs. A few examples will illustrate this method.

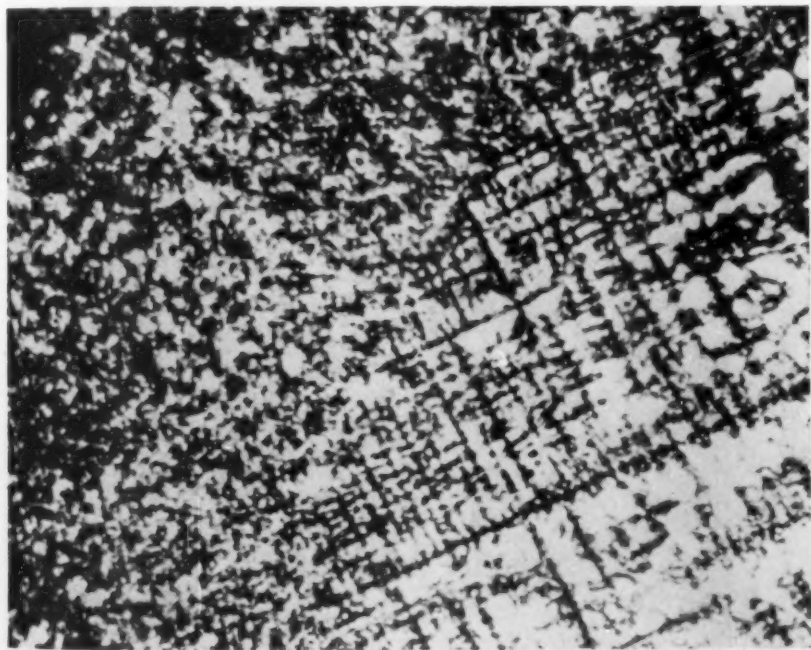


FIG. 13—LEADED BRONZE. TWO GRAINS ARE VISIBLE, ONE IN WHICH THE DENDRITES ARE SEEN FLAT ON AND THE OTHER IN WHICH THEY ARE SEEN END ON. MAGNIFICATION, 50X.

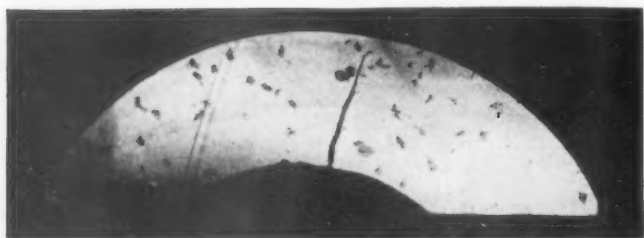


FIG. 14—COLD SHUT IN AN ALUMINUM ALLOY PENETRATES ALMOST TO THE OUTER SURFACE AND IS SEEN AS A BLACK LINE WITH SMOOTH WALLS. MAGNIFICATION, 4X.

20. Figure 14 shows an X-ray micrograph of a common cold shut in a cylindrical section of a casting. Its purpose is to bring out the differences between a cold shut and a crack.

21. Figure 15 shows an X-ray micrograph of a dross inclusion. On the original radiograph this showed as a thin black line which could have been mistaken for a crack. The X-ray micrograph emphasizes the fact that dross does not always give an easily recognized X-ray pattern.

22. Figures 16 and 17 are X-ray micrographs from a bronze gear wheel. Many of these castings had been rejected after expensive machining had

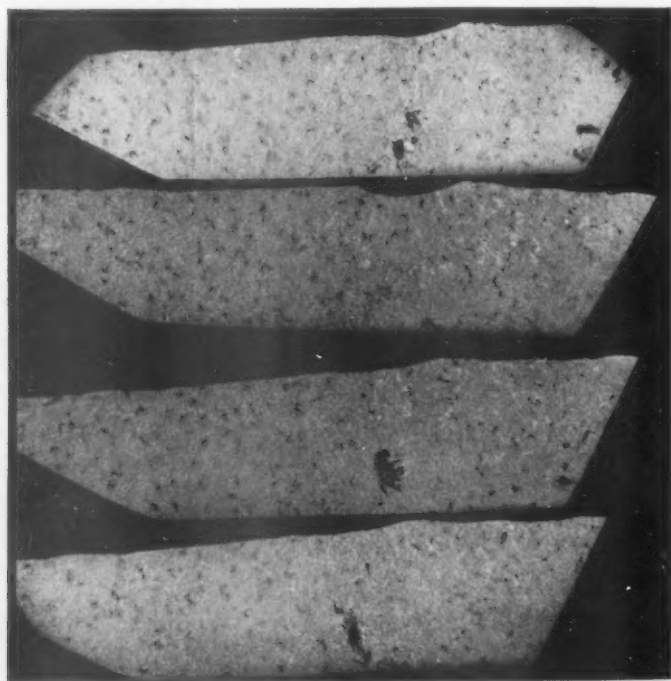


FIG. 15—X-RAY MICROGRAPH OF FOUR SLICES THROUGH A DROSS INCLUSION. MAGNIFICATION, 3X.

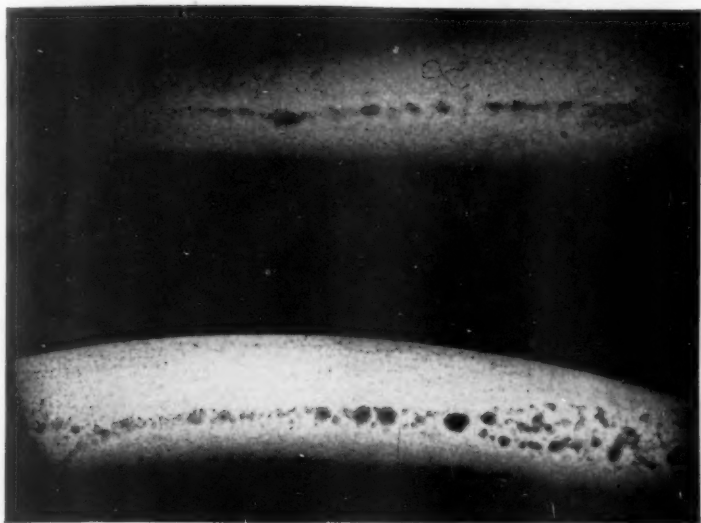


FIG. 16—CENTERLINE SHRINKAGE IN A SMALL BRONZE CASTING. MAGNIFICATION, 2X.

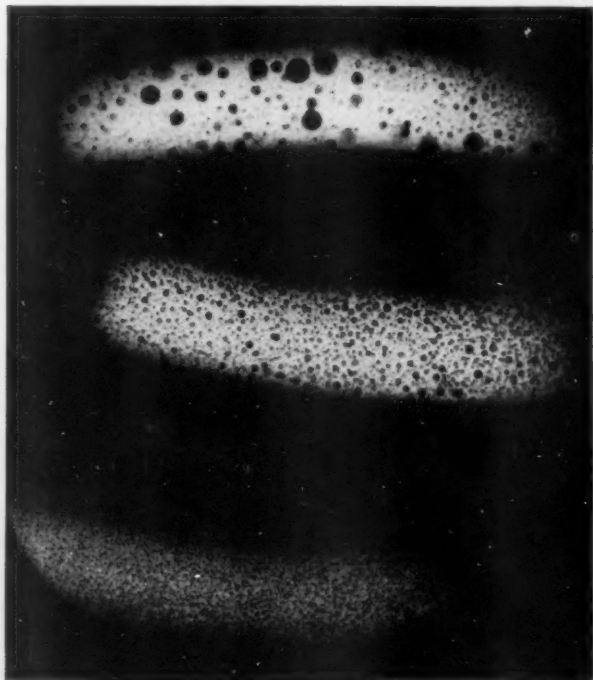


FIG. 17—THREE SLICES FROM A BRONZE CASTING TAKEN NEAR THE COPE SURFACE. LOWER—TINY BUBBLES OF EVOLVED GAS. MIDDLE—SLIGHTLY LARGER BUBBLES FORMED BY COALESCENCE. UPPER—CLUSTER POROSITY AT THE COPE SURFACE. MAGNIFICATION, 2X.

revealed small holes. Ordinary X-ray cut the machining cost 75 per cent by revealing the presence of the holes, but the type and cause of the defect remained in doubt. Figure 16 clearly shows a centerline shrinkage requiring improved feeding; but Fig. 17 shows that pinholes were also occurring and that their elimination required drier or more permeable sand.

23. All of the illustrations so far have been of sand castings. However, X-ray micrography is also a very useful tool in permanent mold and die casting foundry control. Figure 18 shows five adjacent slices from a permanent

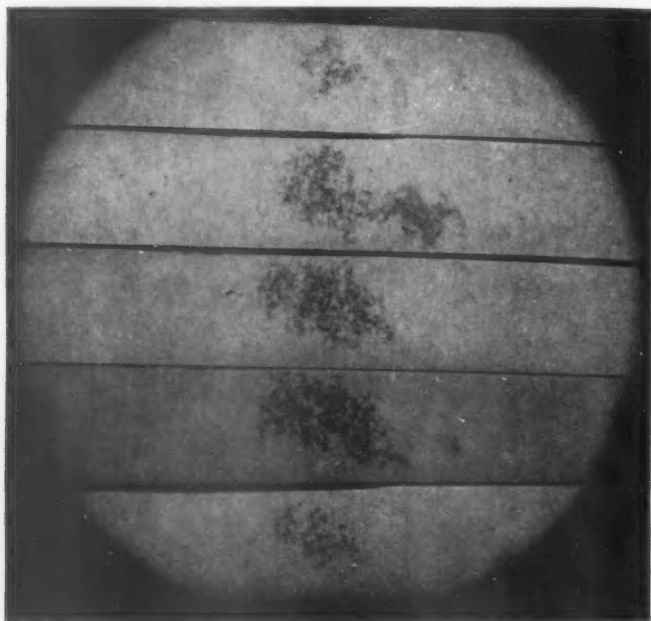


FIG. 18—SPONGE SHRINKAGE IN A PERMANENT MOLD CASTING. MAGNIFICATION, 3X.

mold casting. In this case, the defect as seen on the ordinary radiograph could have been diagnosed as dross, but the X-ray micrograph shows that it actually was due to shrinkage.

24. Figure 19 shows sponge shrinkage in a bronze casting, which also could have been diagnosed as dross.

25. Figure 20 shows three adjacent slices from a high pressure die casting. The purpose of this test was to distinguish between cold shuts and cold shots in the casting. This particular defect appears to be of the type due to the inclusion of a frozen splash of metal.

#### CONCLUSION

26. In conclusion, it should be emphasized that all the illustrations in this paper have been made exclusively by X-ray, and that in all cases the only preparation of the sample was the slicing by the cut-off wheel.





FIG. 19—SPONGE SHRINKAGE IN A MANGANESE BRONZE CASTING. MAGNIFICATION, 10X.

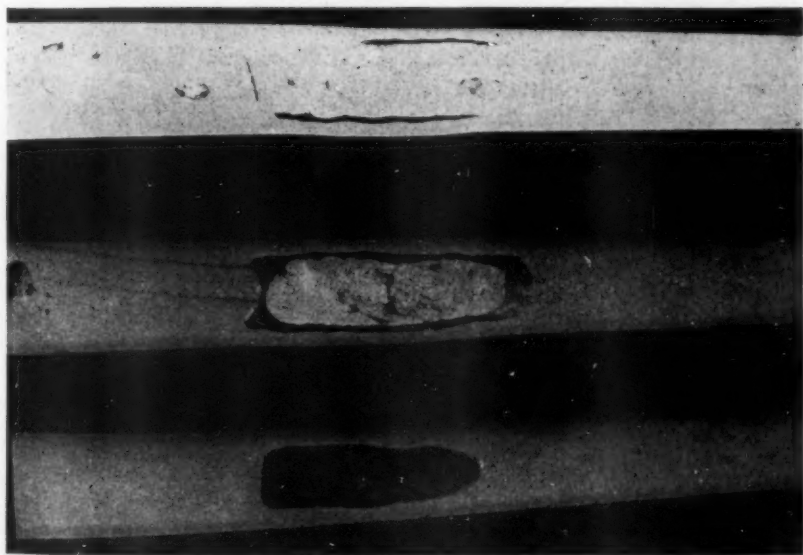


FIG. 20—COLD SHOT IN A PRESSURE MOLD CASTING. MAGNIFICATION, 3X.

*(Discussion begins on following page.)*

## DISCUSSION

*Presiding:* DR. N. E. WOLDMAN, Eclipse-Pioneer Div., Bendix Aviation Corp., Teterboro, N. J.

*Co-Chairman:* W. E. MARTIN, Sperry Gyroscope Co., Flushing, N. Y.

O. J. MYERS<sup>1</sup>: Is it possible to differentiate between burning and microshrinkage in magnesium alloys by this method?

MR. BALL: Distinctions between the presence of oxide and the presence of cavities at the grain boundaries can be recognized by an experienced operator.

For instance, in the aluminum 220 alloy, which contains 10 per cent magnesium, the degree of contrast between the sound and unsound region indicates whether the condition present is that of oxidation or cavity.

J. A. DUMA<sup>2</sup>: The preparation of microradiographic slices of from 0.002 to 0.050-in. thickness is no easy matter, and has given our machinists considerable trouble. Will you kindly clarify the cut-off wheel process? What microradiographic technique would you recommend for showing up the phase structure in a silicon-monel metal, which is an alloy of nickel-copper and silicon? By technique is meant kilovoltage, film, targets, and filters and screens which might be used to bring out the structural phases in that alloy.

MR. BALL: In the preparation of the slices, the cut-off wheel can cut as thin as 0.010 in. with very little trouble. To cut 0.005 in., great care is required in the way the wheel first touches the casting. The metal surface must be at right angles to the wheel and it must be smooth. For ordinary purposes, the as-cast surface is quite all right, but if we are trying to cut very thin slices we must cut into a smooth surface. Fortunately, in all those cases where we have had to have an extremely thin slice, we have required only a small area.

We have thinned down slices from say 0.010 to 0.002 in. by taking a small area, say  $\frac{1}{4}$ -in. sq., and rubbing it by hand on a file. A very smooth file with plenty of oil is best. If we try to thin down an area as large as one sq. in., this process becomes prohibitively slow. The cut-off wheel thickness has an effect on the cutting of thin slices. Wheels of 0.020-in. thickness are very fast, but they are rather flexible. A wheel thickness of 0.032 in. is very suitable for general purposes. A minimum wheel speed of 1000 rpm. is required for accurate slicing.

On the problem of an alloy with silicon, copper and nickel, any normal technique will distinguish between the silicon and the other two metals. We would start at about 40 kilovolts with a thickness of 0.020 in. If the structure within the grain is to be studied, then the thickness of the metal must approximate the grain size of the sample. To distinguish between copper and nickel requires that monochromatic zinc radiation be used. Characteristic zinc radiation corresponds to only 10 kilovolts. This means that an extremely thin specimen would be required. It would be necessary to use a zinc target tube with a copper filter.

J. F. EDNIE<sup>3</sup>: Is there any particular advantage to be gained by using microradiography in the examination of standard bronzes and brasses as against the metallograph? For example, would more structural detail be revealed in a copper-tin-lead alloy, using the former method?

MR. BALL: Not as far as the details seen are concerned. Metallography will bring out some things which x-ray micrography will not, but the latter method has two tremendous advantages. The first is that a greater area can be covered; e. g., we will take a pilot

<sup>1</sup> Wright Aeronautical Corp., Lockland, Ohio.

<sup>2</sup> Norfolk Navy Yard, Portsmouth, Va.

<sup>3</sup> Duquesne Smelting Corp., Pittsburgh, Pa.

casting and say that we want to investigate this whole casting. So we will cut slices from a dozen different locations and lay those slices on top of one plate and x-ray them. Fifteen min. later we have information covering the whole casting.

The second advantage is that the absence of etching means that we can use relatively unskilled labor; e. g., if we are using metallography on a leaded copper alloy, skilled polishing is required to prevent the lead from coming out, or, if we are examining an aluminum-copper alloy, skilled etching is required so that we do not etch out the copper-rich constituent and think we have a cavity. In neither of these cases does the x-ray method require precautions. Another advantage of the x-ray method is that we are not looking at a surface of the metal but at a volume. So there are two main and one minor advantages.

MEMBER: What is the distance from the x-ray target to the film?

MR. BALL: That is quite an important point in technique. In general scientific practice, one starts with the quickest and easiest setup. In this case we start off with a distance of 3 in. from the target to the slice of metal. The metal is so close to the plate that the blurring caused by the size of the focal spot is negligible. However, there are some cases, for instance, the copper-beryllium alloys, in which the images are so very narrow that it is necessary to go up to 6 in. When we are inspecting many slices, we may just take an ordinary commercial x-ray tube and cover an area 17 x 14 in. at 36-in. distance.

J. M. GARDNER<sup>1</sup>: There was a question raised as to whether, in magnesium castings, the difference between burning and microshrinkage could be determined by micro-radiography. I believe that the term "burning" was misunderstood. Mr. Ball apparently was thinking of burning in molten metal, whereas I believe Mr. Myers referred more to burning which shows up on the surfaces as a series of very small blisters, or which shows up as burning of the primary compound which occurs between the grain boundaries.

MR. BALL: I was thinking of a burning of the molten metal, which causes oxide at the grain boundaries.

MR. GARDNER: What about the cavities which occur there?

MR. BALL: I have not investigated this condition, but I am sure that any type of small cavity at the grain boundaries will have certain characteristics which the micro-radiograph will bring out very clearly and which will be easily recognized, once one is familiar with the condition. Because of the absence of etching and because the shapes of the cavities below the surface are revealed, the x-ray method is superior to metallography for studying any cavities up to  $\times 100$  magnification.

<sup>1</sup> Wright Aeronautical Corp., Lockland, Ohio.

# A Study of Molding Methods for Sound Castings

By F. G. SEFING\*, NEW YORK

## Abstract

*Following several years' experience making castings sound, the author has laid down the principles involved. These fundamentals follow scientific principles and yet they are practical. No case has yet come to the author's attention where these principles have not worked successfully when applied to steel or cast iron, the bronzes or light metals. It will be noted that there is nothing complicated in applying the best molding methods for sound castings.*

THE most important feature of any casting is that it be sound. Freedom from casting defects is really as important to the user as the particular composition of metal desired. Indeed, sound castings not only satisfy the customer, but they also insure profit for the foundry and assure repeat business.

Castings free from defects are dependable in service, cost the least to machine and to fabricate into machines, and can command the highest prices for the foundry. That foundry which makes the highest percentage of sound castings has the highest percentage of profit.

To produce sound castings, the greatest attention should be given to the molding details. It is economical and shrewd business to spend money to study those molding methods which make good castings.

The factors involved in molding satisfactory castings are the same for all metals. Let us consider what these factors are and how easily and sensibly they can be applied.

## Gate Design

Clean metal poured into the mold cavity is of first importance. To this end the use of skim gates, slag

traps or swirl gates are effective. In low melting point metals, such as aluminum, the use of coarse steel wool or perforated steel sheet as a skimmer over the sprue is effective.

In aluminum and magnesium pouring, agitation causes the trapping of some of the surface scum. This is prevented by using slotted sprues. The thin, deep slots and the angle of the pouring gates permit the metal to enter the mold with minimum agitation (Fig. 1).

The cross section of gates should be rectangular rather than square or round where they are attached to the casting, except when they are part of the feeding system. The rather thin rectangular gate section promotes more rapid freezing and, therefore, produces soundness at the gate.

The total area of the gates should be sufficient to have the maximum pouring speed without washing the sand. Filling the mold with adequately hot metal, which also means rapid pouring, promotes soundness by giving time for removal of slag and gas inclusions.

## Position of Gates and Risers

Controlled directional solidifica-

\*Research Met., International Nickel Co.

NOTE: This paper was presented at a Gray Iron Castings Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

<sup>1</sup> Superior numbers refer to references at the end of this paper.

tion is not peculiar only to steel foundry practice, where Briggs, Gezelius,<sup>1</sup> and others did the early work, but it should be applied wherever molten metal is freezing. The earliest application of this principle was in making sound steel ingots. By comparing big-end-down, big-end-up and hot-top ingots, it is seen how sound ingots have been controlled in the steel mill (Fig. 2).

The principle involved in controlled directional solidification is based upon the facts that the coldest metal and the smallest sections freeze first, and the direction of freezing shall move toward the heaviest sections and/or the hottest metal in the mold.

Furthermore, there shall be no intermediate light sections or cold metal in this progressive freezing

FIG. 1—RIGHT—MOTOR HOUSING MAGNESIUM CASTING. EXCESSIVE VENTING BY THE USE OF OPEN SAND AND VENT RISERS IS NECESSARY FOR LIGHT METALS.

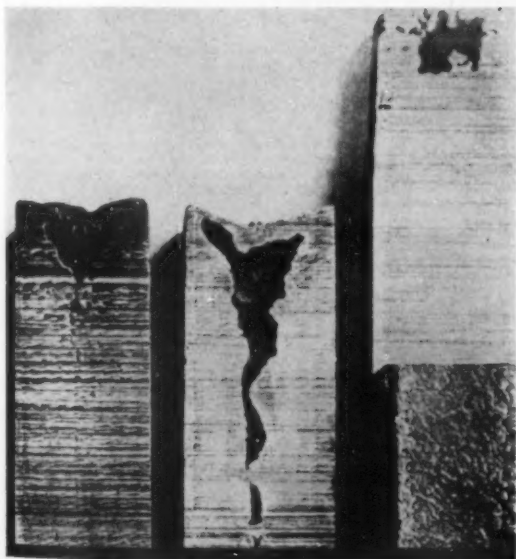
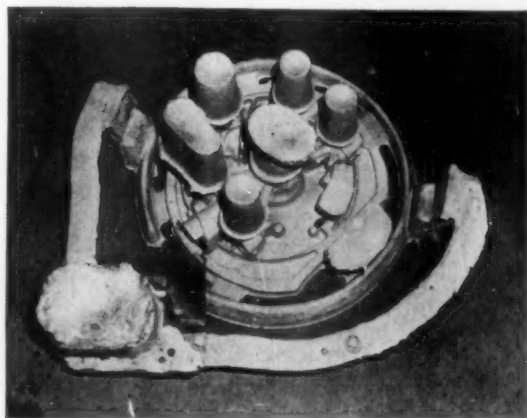


FIG. 2—LEFT—SOUND STEEL INGOT PRODUCTION FOLLOWS PRINCIPLE OF CONTROLLED DIRECTIONAL SOLIDIFICATION. INGOT AT RIGHT WAS KEPT MOLTEN WITH "HOT TOP."

which would freeze early and prevent progressive feeding. Figures 3 to 12, inclusive, show how this principle is used.

### Helping Risers to Feed

This involves several simple details (Fig. 18).

1—We must have the design such that the riser is heavier than the section to be fed to be sure the riser freezes after the casting. Further, the design must be such that the riser connection will freeze after the casting.

2—The metal in the riser must be as hot or hotter than the metal in the castings (Figs. 4, 8, 10, 11, 12).

3—The riser should be kept open to allow the atmospheric pressure to assist gravity in pushing the metal into the casting (Fig. 8).

4—The riser should be high enough to afford plenty of hydrostatic pressure (Figs. 13, 14, 15).

High risers provide greater hydrostatic pressure to assist in securing soundness by pushing gas, slag, etc., up through the liquid metal and out of the casting. This same liquid pressure of the molten metal assists in feeding the casting.

Proper riser design and hot metal in the riser are really applications

of the principle of controlled directional solidification.

To have risers contain the hottest metal in the mold, the metal should be poured by gating through the riser. When this cannot be done, hop-topping the riser with an auxil-

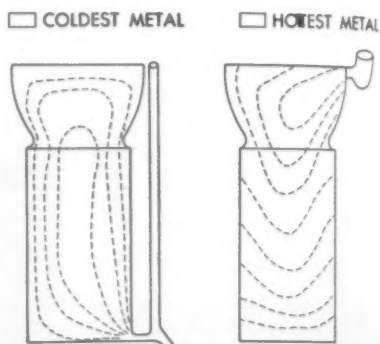


FIG. 3—EFFECT OF TOP AND BOTTOM GATING ON TEMPERATURE DIFFERENTIAL. POSITION OF INGATE CONTROLS THE POSITION OF THE COLD AND HOT METAL IN THE MOLD CAVITY.

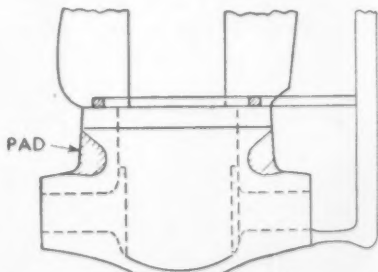
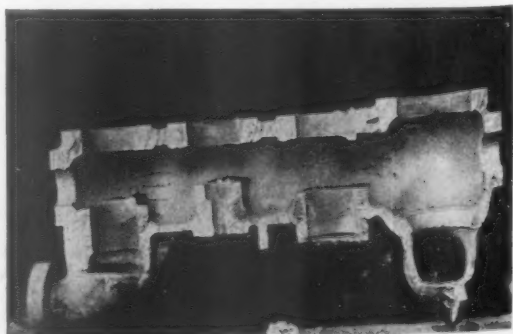


FIG. 4—PADDING FOR CONTROLLED DIRECTIONAL SOLIDIFICATION. USE OF PAD TO PROVIDE PROGRESSIVE FREEZING FROM THE THIN TO THE HEAVIEST SECTION.

FIG. 5—RIGHT—DESTROYER THROTTLE VALVE STEEL CASTING APPROACHING THE ULTIMATE IN POOR DESIGN. NOTE THE MANY LIGHT AND HEAVY SECTIONS.





ary ladle of metal will accomplish the same purpose.

Risers should have 50 per cent greater cross section or, simply the thickness of the riser should be 50 per cent greater than the thickness of metal to be fed. Risers attached to the side, particularly in gray iron, promote greater soundness than top risers.

#### *Atmospheric Pressure Feeding*

Atmospheric pressure feeding is accomplished by covering risers with insulating compounds to prevent a skin of metal freezing over the top, and thus permit the atmosphere to

push the metal down the riser. Blind risers and shrink bobs are of questionable value unless kept open to the atmosphere with core rods, which should extend from the sand of the mold through to the center of the blind riser. This device was patented by John Williams<sup>3</sup> in 1940 and is illustrated in Fig. 16.

#### *Riser Connections*

Riser connections to the casting should have a reduced cross section and be as short as possible (Fig. 18). Riser connection dimensions of not more than 1/3 of the casting section dimensions have been found



FIG. 6—LEFT—UN SOUNDNESS IN BRONZE CASTINGS CAUSED BY IMPROPER APPLICATION OF RISERS. METAL BRACKETED BY ANGLE IS A BLIND RISER. THESE RISERS CAUSED SHRINKAGE UNDER THEM. THE GATES ENTER A THIN SECTION OPPOSITE A HEAVIER SECTION (ARROWS).

FIG. 7—RIGHT—SAME CASTINGS AS SHOWN IN FIG. 6. NOTE THAT THE CASTINGS WERE TURNED IN ORDER TO GATE THROUGH THE HEAVY BOSS, ELIMINATING THE NEED OF RISERS, WITH EXCELLENT RESULTS.

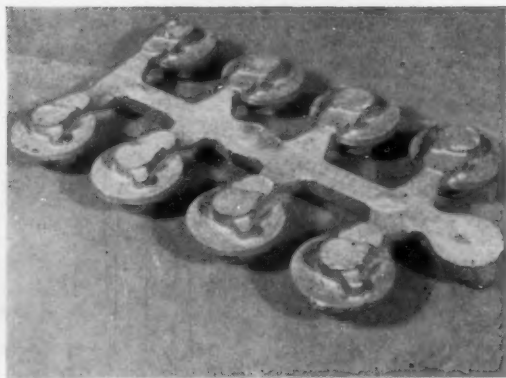




FIG. 8—BRONZE CASTING GATED THROUGH THE RISER. THE COLDEST METAL AT END FARTHEST FROM RISER. FREEZING PROGRESSES TO THE HOTTEST METAL AT THE RISER END. THE LONG RUNNER WAS USED TO ACCOMMODATE THE FLASK EQUIPMENT, BUT THE LENGTH MAY BE SHORTENED. HORN ENTERS RISER AT BOTTOM. THIS METHOD OF POURING PRODUCES CLEANER CASTINGS THAN WHEN POURED ON END. TYPE OF GATING SHOWN IS PRACTICAL AND EFFECTIVE.

very satisfactory. For example, a  $1\frac{1}{2}$ -in. diameter or  $1\frac{1}{2} \times 1\frac{1}{2}$ -in. connection is the maximum that need be used for a 6-in. thick riser to feed a 4-in. section.

The relationship of riser to the casting dimensions is given in Fig. 18. Note that the riser extends below the connection by the same dimension as the riser thickness. The purpose of depth of riser below the connection is to have adequate

volume of metal to prevent freezing ahead of the riser connections. Of course, the height of the riser must be great enough to prevent the shrinkage in the riser from extending below the riser connection.

Fig. 18 shows a thin wall of core sand between the riser and casting, which sand becomes incandescent and which permits the riser connection to remain fluid. This core plate varies from  $\frac{1}{2}$  to  $1\frac{1}{2}$  in., depending on section thickness.

This method of riser attachment promotes greater soundness under the riser and permits of its easy removal. Generally, a sledgehammer blow will remove the riser, since the connection is essentially a deep notch.

#### *Use of Chills or Denseners*

Chills or denseners are used where risers cannot be conveniently placed, or to control the freezing rate. Their purpose is to do the same job as feeders by freezing the metal about as rapidly as it is poured and, therefore, risers for feeding are unnecessary.

Indeed, when chills are used great care must be exercised that the feeders are so placed that they are not

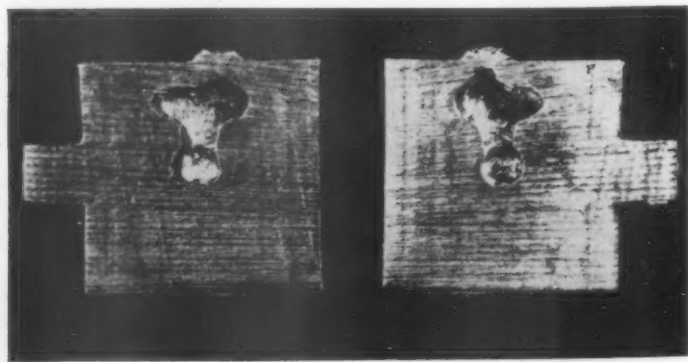


FIG. 9—STEEL CASTING SECTION SHOWING SHRINKAGE CAVITY. (Courtesy, American Steel Foundries.)

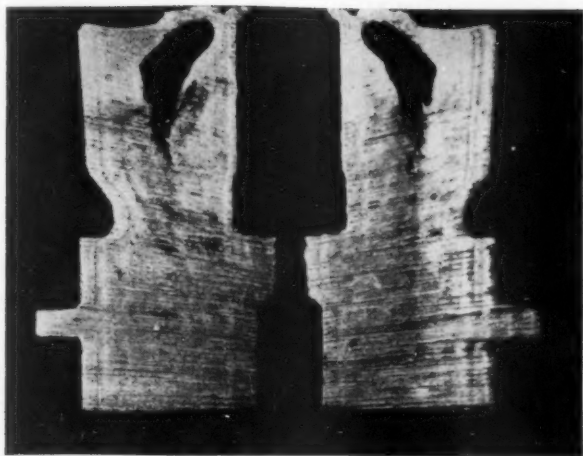


FIG. 10—SAME CASTING AS SHOWN IN FIG. 9. SOUNDNESS INSURED BY USE OF ADEQUATE RISER.

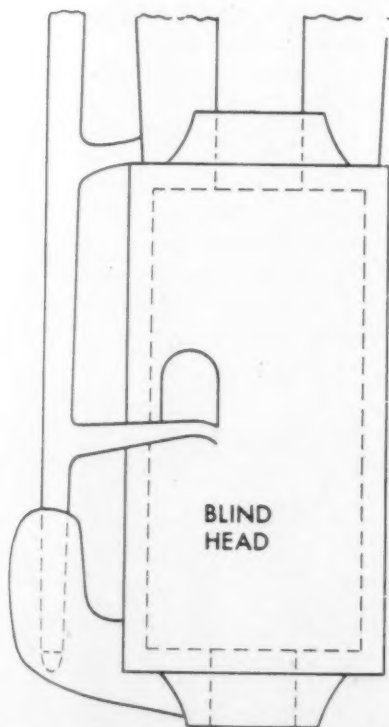


FIG. 11—STEP-GATING AND POURING THROUGH RISERS. THESE GATES PERMIT THE FIRST METAL TO REMAIN AT THE BOTTOM, THE NEXT AT THE CENTER, AND FINAL INTO THE CASTING'S TOP.

close to chills and do not counteract the chill effect. Chills cause the shrinks to move somewhere else, unless they are placed with due regard to controlled directional solidification.

There are certain points regarding chills that must be kept in mind:

(A) Chills must be clean. Slightly oxidized or rusty chills cause blows to develop in the casting next to the chill. Before each use, therefore, they should be sand blasted and preferably wiped with kerosene to prevent slight rusting in the mold.

(B) They must not burn the casting. Chills are protected from "burning-in" by using chill coatings, of which the writer has found several mixtures to be effective. A commonly used coating is silica flour and linseed oil mixed to a thin-paint consistency. This coating requires heating to dry the surface.

Pouring over a chill or excessive agitation of the metal against the chill tends to cause "burning-in." The aim should be to have the mold

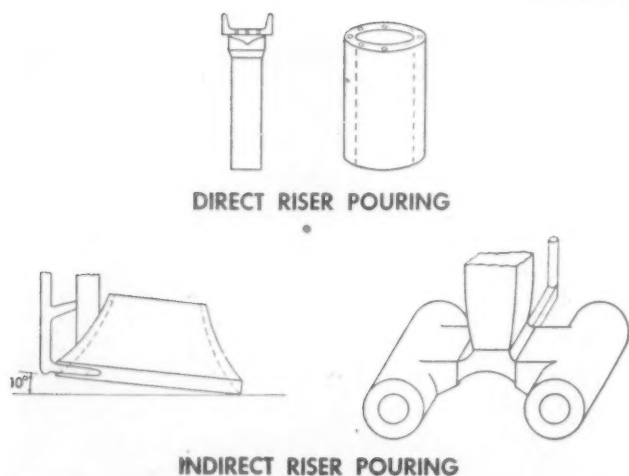


FIG. 12—EXAMPLES OF GATING TO PROVIDE THE HOTTEST METAL IN THE BEST POSITION FOR FEEDING.

poured before the chills have had any time to warm up.

(C) Chills must be large enough to penetrate their densifying effect across the section to be chilled, but not so large and sprawling that they prematurely freeze the metal in the lighter or adjacent sections. Precautions must be taken to prevent chilling the metal beyond the section to be densened, or else the metal cannot feed the densified portion of the casting.

(D) Chills should be on the side or bottom of the mold cavity for most effective chilling.

(E) They are most effective when the metal moves up to them and is not agitated further. Where possible chills should be furthest removed from the gates so that when the metal pours against the chill, freezing commences.

(F) Rapid pouring permits the chill to do its most effective work. Rapid pouring permits filling the

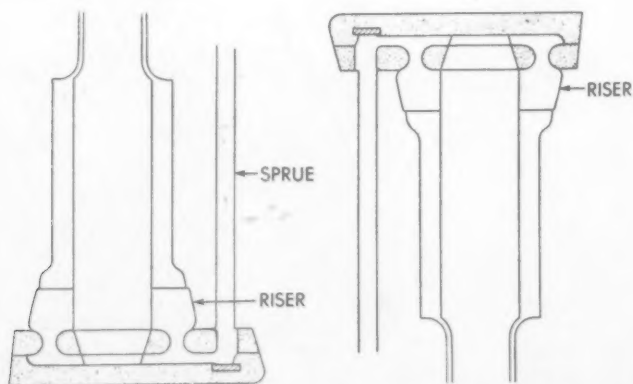


FIG. 13—TOTAL REVERSAL METHOD OF GATING AND RISERING. COMPLETE REVERSAL OF THE CASTING FOR FEEDING. POURED IN POSITION AT LEFT, THE MOLD IS REVERSED AFTER FREEZING THE SPRUE SO THAT THE HOT RISER CAN FEED THE CASTING BY GRAVITY.

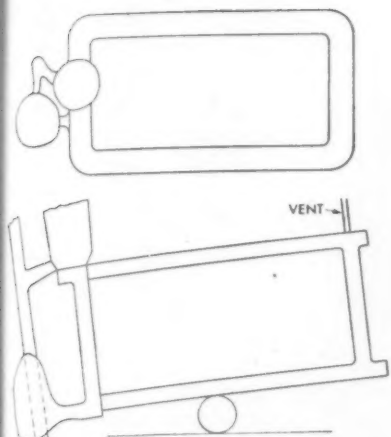


FIG. 14—PARTIAL REVERSAL METHOD OF GATING AND RISERING. MOLD IS TILTED AFTER POURING TO PROVIDE HYDROSTATIC PRESSURE.

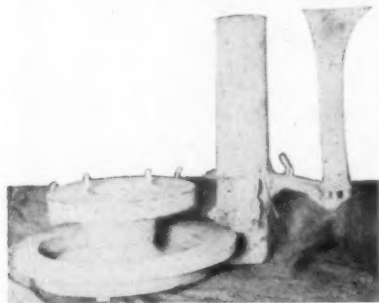


FIG. 15—SUCTION COVER MADE OF GOVERNMENT BRONZE. THIS CASTING WAS SUBJECT TO LEAKAGE AND CHILLS, AND RISERS FAILED TO OVERCOME THE DIFFICULTY. THE METHOD OF GATING AND RISERING SHOWN FINALLY PROVED SUCCESSFUL. RISER IS 3 IN. IN DIAMETER AND STANDS 10 IN. ABOVE CASTING. NO RISER OVER THE CASTING. NOTE STRAINER CORE AND LARGE FILLET WHERE METAL ENTERS RISER. THE COLDEST METAL IS FARTHEST FROM RISER AND FREEZING PROGRESSES TOWARD THE RISER THUS ASSURING SOUNDNESS.

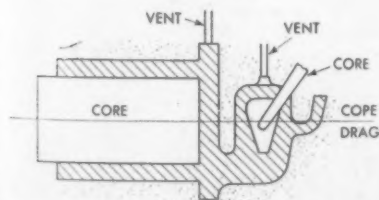


FIG. 16—ATMOSPHERIC PRESSURE FEEDING, ILLUSTRATING THE PRINCIPLE OF THE WILLIAMS ATMOSPHERIC RISER.

mold with minimum warming up of the chill. If the chill has had time to warm up considerably before pouring is complete, or before the metal in contact with the chill is quiet, the effectiveness of the chill is reduced.

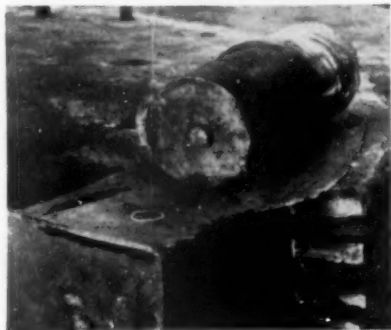


FIG. 17—EXTREME APPLICATION OF KNOCK-OFF RISERS. RISER IS 12 IN. IN DIAMETER, "HOT TOPPED" FOR A 16-IN. BY 14-IN. BY 22-IN. SECTION. RISER CONNECTION IS 2 IN. IN DIAMETER.

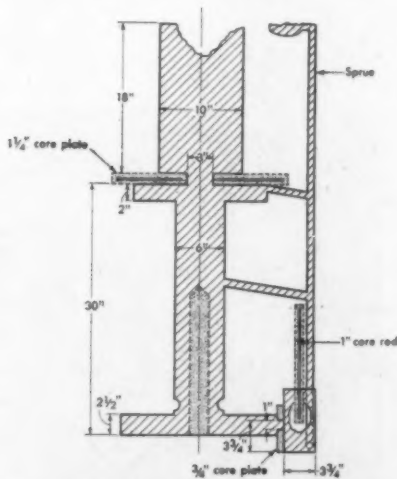


FIG. 18—MOLD SHOWING RELATIVE DIMENSIONS OF RISERS AND RISER CONNECTIONS AND ATMOSPHERIC RISERS. CASTING INVOLVED STEP GATES, WILLIAMS RISERS, GATING THROUGH THE RISER AND KNOCK-OFF RISERS. READER SHOULD TRACE THE FREEZING FROM THE THINNEST SECTIONS AND COLDEST METAL TO HEAVIEST SECTION AND HOTTEST METAL IN THE RISERS.

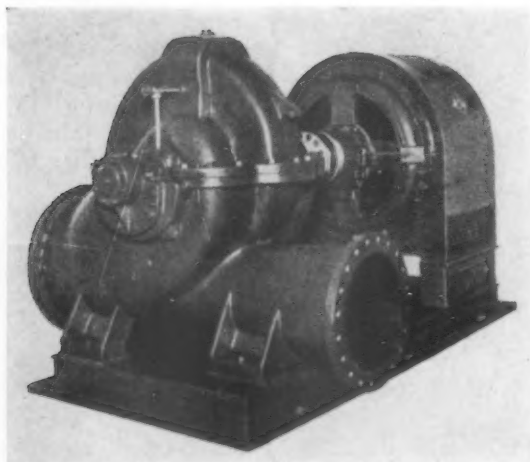


FIG. 19—LEFT—PUMP CASTINGS SHOWING METAL JOINTS THAT WOULD MOST LIKELY REQUIRE CHILLING FOR PRESSURE TIGHTNESS.

### *Venting Mold Cavities*

The importance of venting mold cavities is realized by observing the torch effect often blowing out of a riser or vent during pouring. "Whistlers" is a term applied to vents. When pouring light metals, like aluminum and magnesium, special venting is necessary to prevent

mold back pressure and to help fill the mold.

All dead-end spots of a mold cavity should be vented so that the metal runs without restraint to every portion of the mold. Also, we must remember that if gas pressure is developed in a mold there is an increased tendency to force gases into the metal and cause defects.



FIG. 20—PUMP IMPELLERS OF LARGE DIAMETER AND NARROW VOLUTES REQUIRE SPECIAL FOUNDRY TECHNIQUE. (Courtesy, Le Courtenay Co.)



Vents are best designed to be rectangular at the casting to prevent openness and pinholes at the junction with the casting.

A thorough undersanding and application of only a few principles is necessary to make sound castings.

(1) Pouring gates should be designed so that clean metal enters the mold quietly and rapidly. Rectangular gate cross sections are preferred to square or round sections.

(2) Controlled directional solidification assists the freezing of the casting to begin at the coldest metal and/or to the thinnest section, and to move progressively toward the

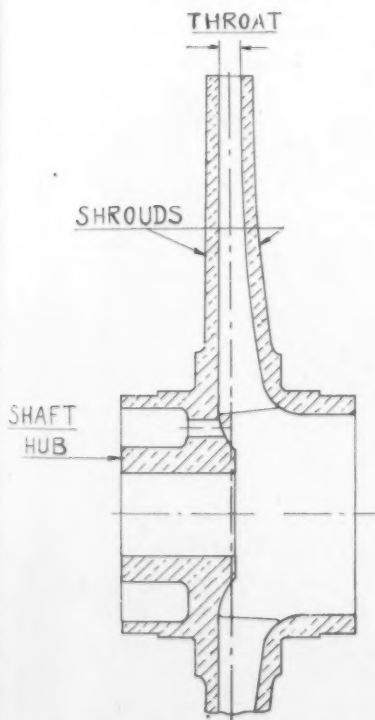


FIG. 21—SECTION OF LARGE IMPELLER SHOWN IN FIG. 20. METAL POURED WITH THE AXIS HORIZONTAL THROUGH RISER ATTACHED TO THE HUB, POURED RAPIDLY AND FREELY VENTED WITH RECTANGULAR VENTS AT THE TOP OF BOTH SHROUDS.

hottest metal and/or the heaviest sections.

(3) Design and pour risers so they will assuredly feed castings by conforming to the principles of controlled directional solidification. Allow plenty of pressure to act on the molten metal in a feeder.

(4) Knock-off risers are convenient to remove and they feed adequately.

(5) Chills or denseners are used where risers are impracticable, or where we wish to assist the freezing rate.

(6) Adequate venting of the mold cavity permits filling the mold easily by preventing back pressure. Gas absorption by the metal in the mold is also reduced by good venting. A variety of castings is made, complete records of the successful molding

In a job shop, where a wide variety of castings is made, complete records of the successful molding practice of each casting should be kept. The best record is a photograph of the casting as poured indicating all gates, feeders and chills, and marking all dimensions. At any future date, the casting can be made without trouble by referring to the record.

The future of any foundry, in fact, of the foundry industry, hinges largely upon its ability to make sound castings consistently.

#### ACKNOWLEDGMENT

The writer wishes to express his appreciation especially to C. W. Briggs of the Steel Founders' Society, H. F. Taylor of the Naval Research Laboratory and Joseph Nixon of the Whitehead Metal Products Co. for the detailed instruction received on the principles for making sound castings. Further appreciation is expressed for the many suggestions given by the writer's associates of the International Nickel Co. and to the

many foundrymen with whom the writer has had the opportunity to work in proving that sound castings are made by following fundamental scientific principles.

### References

1. Briggs, C. W., and Gezelius, R. A., "*Studies on Solidification and Contraction in Steel Castings*," TRANSACTIONS, American Foundrymen's Association, vol. 41, pp. 385-448 (1933), vol. 42, pp. 449-476 (1934), and vol. 43, pp. 274-302 (1935).
2. Brinson, S. W., and Duma, J. A., "*Application of Controlled Directional Solidification to Large Steel Castings*," TRANSACTIONS, American Foundrymen's Association, vol. 48, pp. 225-282 (1940).
3. U. S. Patent No. 2,205,327, "*Means for Casting Metals*," John Williams.
4. Taylor, H. F., and Rominski, E. A., "*Atmospheric Pressure and the Steel Casting—A New Technique in Gating and Riser*," TRANSACTIONS, American Foundrymen's Association, vol. 50, pp. 215-259 (1942).
5. Reid, J., and Nixon, J., "*The Making of Intricate Ni-Resist Castings*," NICKEL CAST IRON NEWS, September and November, 1939.
6. Reichert, W. G., "*Factors in the Production of Quality Castings*," THE FOUNDRY, vol. 72, no. 3, March, 1944, pp. 114, 115, 190-195.

# The Melting of Non-Ferrous Metal in the Cupola

BY LEIGHTON M. LONG,\* TOLEDO, OHIO

## Abstract

*The iron-melting cupola has been used to melt copper for the making of brass or bronze. Its use, however, has been for the most part a matter of expediency, because in an iron foundry no other suitable furnace is usually available. The customary procedure generally followed has been described in another paper on the basis of notes furnished by W. H. Rother, of the Buffalo Foundry and Machine Co., but it was limited to the melting of copper and the addition of the alloying elements was made to the molten metal in the ladle. No reference was made to the melting of a pre-alloyed composition.*

*In this paper the author describes the design and operation of cupolas for melting pre-alloyed copper-base alloys. He also gives the advantages of cupola melting for non-ferrous metals.*

1. In recent years some of the larger bronze foundries, in order to satisfy the need for an uninterrupted supply of metal to maintain highly mechanized molding production, have developed a specially constructed cupola. Mauland<sup>1</sup> in 1931 described the advantages of this furnace and present day design and operation have enhanced them.

2. The successful operation of this cupola, in the manner herein described, has been due to the fuel used, namely a coke made from coal-tar pitch. Coke from this base is 99 per cent carbon. Because of its low sulphur and ash content and its extremely high shatter-strength, it is a fuel free from contaminating elements and slag-producing oxides, and provides an ideal, openly spaced melting zone requiring very low blast pressures. Ordinary foundry coke can be used, but does not allow enough flexibility after the first three hours operation, due to the slag accumulation, as will be explained under *Slag Control*.

## DESIGN

3. The furnace in use today (Fig. 1) is a modified type of cupola having a 42-in. shell lined down to 26 in. The openings at each of the four tuyeres are approximately 6 sq. in. in area with their centers 16 in. above the base and 72 in. below the charging door. The shell and stack (20 ft. above charging door) are lined with fire brick. An inner brick or monolithic lining of silicon carbide extends from the base to a point 28 in. above the tuyeres. Charges are introduced either from a charging platform or by a skip hoist. A maxi-

\*Consulting Engineer.

<sup>1</sup> Mauland, T., "Cupola Melting of Brass," TRANSACTIONS, American Foundrymen's Association, vol. 39, pp. 602-605 (1931).

NOTE: This paper was presented at a Brass and Bronze Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

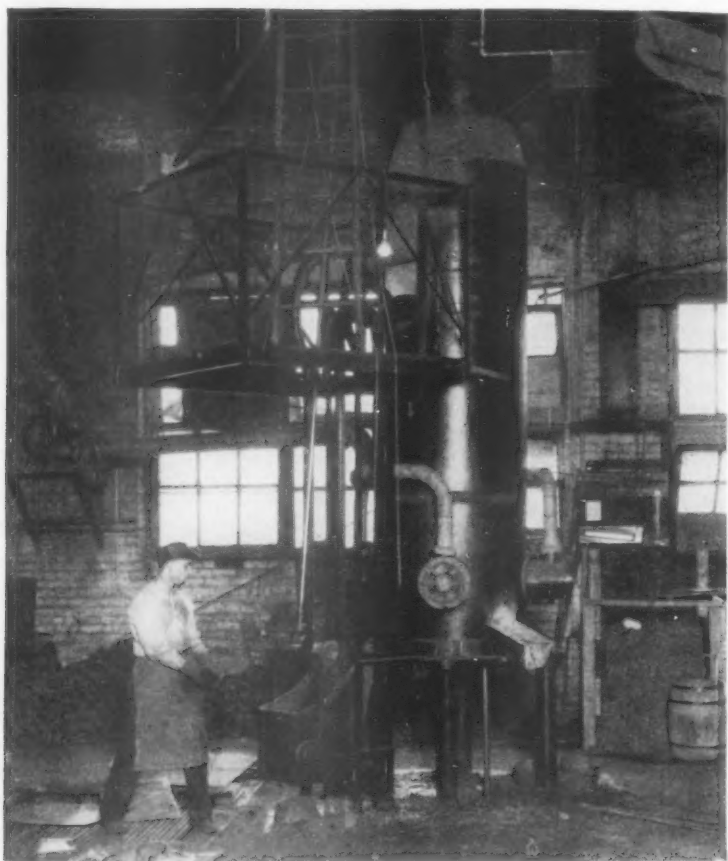


FIG. 1—CUPOLA USED FOR MELTING NON-FERROUS METAL.

mum air flow of 700 cfm. at four ounces pressure is supplied by any suitable blower but a constant volume or positive displacement blower equipped with air-weight control is to be preferred.

#### *Refractory Installation*

4. The secondary fire brick lining, if properly installed, should last indefinitely. Insulation against heat losses below the tuyeres is important and expansion through the melting zone must be considered. The best grade of insulating fire brick, set up on end, is placed around the base up to the tuyeres. Fire brick "splits" are then set up on end around the heating zone approximately 30 in. above the tuyeres. Circle brick or cupola block may then be used up to the stack and the latter should be lined with ordinary fire brick laid flat.

5. The inner lining can be made of silicon carbide circle brick and tuyere blocks which are now stock items, but for the greatest efficiency a monolithic

lining of the best grade of silicon carbide cement is rammed in, using a two piece removable form. Silicon carbide has been proved to be superior to all other lining materials for melting the phosphor bronzes regardless of furnace type, except where crucibles are used. Actual experiments with other refractories in this cupola have shown that the lining life of the silicon carbide exceeds all others by many times, and this property more than outweighs the high initial cost. The tuyere openings, tap hole and rear knock-out opening are cut out after the entire inner lining has been rammed in place. A wood fire maintained for 24 hours will completely dry out and "set" the lining and make it ready for service.

### OPERATION

#### *Preheating*

6. The one-piece hinged bottom door is braced in place and used molding sand is introduced through the rear opening and hand-rammed over the entire bottom. Kindling wood (no nails) is then laid in and the opening is closed with two cupola blocks set in used molding sand. Two hours before charging time the wood is fired and the bed is built up with pitch coke, using natural draft only. It is important that the linings below the tuyeres and the bottom be well heated, otherwise the initial charge passing through the furnace will be cold. The fire, therefore, should not be built up with coke too rapidly. Thirty minutes before charging time the air is turned on and the bed charge is built up to 36 in. above tuyeres. The tap hole is left open until after the initial charge is made. The bed should be incandescent through to the top before first charge is introduced.

#### *Charging*

7. In continuous operation, charges of 400 to 450 lb. have proved satisfactory. Coke in the ratio of 1:20 should be placed on top of each charge. As many charges as desired may be lapped upon each other. If a skip hoist is used, extra coke must be added occasionally, dumping slowly to place it at the rear of the bed. The bed height should be held at all times between 28 and 36 in. above the tuyeres. Metal temperatures are controlled by the height of the bed in relation to the rate of charging and the air flow. The initial charge will require maximum bed height as it receives no preheating; succeeding charges when lapped upon each other will be preheated by the combustion of gases above the bed. These charges will, therefore, require a lower bed; otherwise the metal will be superheated. For highest efficiency including the control of temperature to prevent volatilization losses, the charges should be placed at regular intervals as predetermined by the demand. The cupola is filled to the charging door only when maximum capacity is needed. The melting rate should not fall below 2500 lb. per hour. Melting below this rate in this furnace requires additional coke and retarding or completely shutting off the air supply periodically. In such cases the bed

must be refueled and brought to high temperature before more metal is charged, and unless it is carefully controlled this operation will sometimes cause overheating of the furnace lining. Overheating not only decreases the lining life but has been known to introduce silicon into the metal.

8. The initial charge of 400 lb. will be completely melted in 12 to 14 minutes. By charging the metal and coke in layers, as in iron practice, a maximum capacity of 6000 lb. per hour can be readily obtained. The total metal in the stack at times can reach 2200 lb. equal to five or more charges. The usual average production over an eight hour period is 4500 lb. per hour.

#### *Air Supply*

9. The air flow is adjusted according to the metal demand. With automatic air weight control the supply can be set for a definite melting rate, and the coke bed height and the rate of charging can be established for each composition to give a definite amount of metal at a definite temperature.

#### *Charges*

10. The nature of the charges has a decided effect upon the melting rate. A charge consisting entirely of borings can be melted, but the rate is decreased since they blanket the bed, the temperature of the melting zone is lowered, and the slag that may be present in front of the tuyere openings congeals. An all-ingot mix melts slowly because of its mass. The temperature of the furnace, however, is not affected and as no slag forming substances are introduced, efficient operation is realized. The best results are obtained by keeping the charges uniform and holding the borings below 30 per cent. The sand should be blasted or rattled off all gates and risers and scrap, and it is advisable not to add any unclean metal or slag-forming fluxes. The entire charge must be pre-alloyed metal. Copper, tin, lead or zinc as such must not enter the furnace as part of the charge.

#### *Slag Control*

11. With uninterrupted operation it is possible to melt at peak capacity for sixteen hours. Generally, however, shut downs and metal changes are necessary and when these occur, the temperature of any slag that has been formed is reduced, causing it to congeal around the coke at the tuyere openings. In melting bronze in a cupola, the temperature of the molten metal is considerably below that of grey iron. The temperature of the slag and of the furnace bottom is maintained by the heat of the molten metal. As the softening point of the slags formed are in the neighborhood of 1965 °F., they congeal very readily with a slight drop in metal temperature. Under these conditions, the maintenance of an adequate air supply through the coke bed after eight hours operation is difficult. Keeping the area in front of the tuyeres open by poking the coke and slag away will sometimes be helpful, but when the condition in the furnace has reached this stage, melting speed is too low to



meet demands. It is not necessary to have a slag notch when using the special high carbon fuel. The air pressure is not high enough to direct any slag toward the notch and the temperature of the slag is seldom high enough to keep it fluid. There are fluxing materials that can be used to thin the slag at these temperatures but best results are obtained by allowing no slag forming material to enter the furnace and by keeping the furnace temperature high enough at all times so that the greater part of any slag that is formed can follow the metal through the tap hole. Efforts to use a slag notch and flux the slag off have not proved to be satisfactory where flexibility is desired.

#### *Volatilization*

12. Depending upon the alloy composition, the volatilization losses of the constituent metals will be:

Copper	.....	none
Tin	.....	negligible
Lead	.....to 10 per cent.....	15 per cent
	10 to 15 per cent.....	20 per cent
	15 to 30 per cent.....	25 per cent
Zinc	.....to 3 per cent.....	50 per cent
	3 to 6 per cent.....	60 per cent

For example, an alloy containing 83 per cent copper, 7 per cent lead and 3 per cent zinc will lose 1.05 per cent lead and 1.50 per cent zinc.

#### *Coke Ratio*

13. The operating coke to metal ratio should average 1:20. The average over-all ratio depends on the weight of coke used to pre-heat (about 700 lb.), metal changes, intermittent operations and shut-downs.

#### *Changing Alloys*

14. Since approximately 30 minutes are required to drain the furnace completely after the last charge is introduced, changing from one alloy to another requires approximately the same time. The initial charge of the change-over can precede the 30 minute draining interval by 12 minutes. As a practical precaution, the first 200 lb. of metal should be pigged. When changing from one alloy to another the usual analytical control technique is used, that is, a low leaded content alloy cannot follow a higher leaded alloy and hold the analysis of the initial charges. Charges of similar composition can be rotated and the desired results obtained by following the foregoing procedure. The laboratory can establish "loss" and "pick-up" indices on the various changeovers to control the necessary additions and eliminate any pigging.

#### *Melting High Lead Alloys*

15. This cupola can be used satisfactorily for melting high lead alloys (over 15 per cent). The utmost precaution is necessary, however, to maintain

uniformity of the furnace operation, otherwise the lead content in the melt will fluctuate above or below the accepted tolerances. The calculated lead content of the charge should be held to the lowest point possible compatible with maximum allowable additions of lead to the ladle.

#### *Dropping Bottom*

16. When the furnace has drained completely, the air supply is shut off and the hinged bottom is dropped. It is seldom that the remaining bed will fall of itself. The blocks are removed from the rear opening, the bed is poked and broken loose, and all slag and coke adhering to the side walls are removed.

#### *Lining Repair*

17. The lining can be chipped out and patched after eight hours. The same grade of silicon carbide cement is used for patching as for the lining. A monolithic lining lends itself to patching better than a brick lining. It is possible to resurface the entire lining. The life of brick linings averaged 125 tons melted metal while with monolithic linings the production was increased to 300 tons.

### ADVANTAGES OF CUPOLA MELTING

18. The melting of copper alloys in the cupola is rapid and economical. It is extremely advantageous where an uninterrupted supply of metal is required. Furnaces require little floor area and because of their noiseless operation and low heat radiation, they can be placed in close proximity to molding operations. The tap hole should be canopied with a high velocity exhaust. The melting loss is low and the product is clean and high in quality.

### ACKNOWLEDGMENTS

19. The author is deeply appreciative of the assistance of Dr. E. E. Markaker, Mellon Institute, in preparation of this paper; and of the helpful suggestions of Mr. Garnet P. Phillips, International Harvester Company; Mr. John Grennan, University of Michigan; and Mr. F. E. Fisher, Chicago Ordnance District.

### Bibliography

- Anon., "Melts Bronze in the Cupola," *THE FOUNDRY*, Dec. 1, 1929, vol. 57, no. 23, pp. 1010-1011.
- Anon., *BRASS WORLD*, Sept., 1929, p. 18.
- Alvin, W. C., "Melting Nonferrous Alloys in a Cupola Type Furnace," *TRANSACTIONS, AMERICAN FOUNDRYMEN'S ASSOCIATION*, vol. 42, pp. 737-744 (1934).
- Darby, E. R., "Cupola Melting of Bronze," *METALS AND ALLOYS*, November, 1930, vol. 1, no. 17, pp. 812-813.
- Mauland, T., "Cupola Melting of Brass," *TRANSACTIONS, AMERICAN FOUNDRYMEN'S ASSOCIATION*, vol. 39, pp. 602-605 (1931).
- Mauland, T., "Control Temperatures in Cupola Bronze Melting," *THE FOUNDRY*, July 1, 1931, vol. 59, no. 13, pp. 64-65.

## DISCUSSION

*Presiding:* W. ROMANOFF, H. Kramer & Co., Chicago, Ill.

*Co-Chairman:* G. K. DREHER, Ampco Metal, Inc., Milwaukee, Wisc.

A. K. HIGGINS<sup>1</sup> (*written discussion*): Mr. Long is to be congratulated on his concise presentation of a subject of current interest. His logical reasons for the choice of materials and practice used are especially admirable. Cupola melting of non-ferrous alloys probably has had much less prominence than it deserves because of a general lack of understanding of the factors involved.

I had hoped that Mr. Long would care to deal at more length with some of the limitations and hazards of this type of melting, and with the "batch" type of melting that is so effective for single large heats.

Among the hazards, I would include the atmospheric disposal of approximately 170 lb. of lead that would be lost in a day's run on a 15 per cent lead alloy. Except in wind-swept and sparsely populated districts, an extremely tall stack might be required on the cupola. This would also hold true for the zinc loss, for which the hazard would be less, but the complaints probably greater.

Mr. Long has concerned himself with the true bronzes which can be satisfactorily handled. It might not be amiss to point out that many of the so-called bronzes, containing large amounts of zinc or aluminum, are not amenable to cupola melting. Loss of zinc, as indicated in Mr. Long's data, is enormous, and it is not practical to make ladle additions to compensate when the addition amounts to more than a few per cent. Aluminum, when contained in cupola-melted alloys, is rapidly oxidized and, because the oxide is not volatile, is retained as an extremely viscous slag that causes bridging and may even block off the cupola to such an extent that it is not possible for metal to be tapped. We have not had experience with silicon bronzes, but we suspect the same difficulty would arise in that case.

Where brass foundries are operated in conjunction with iron foundries, it has often been found expedient to use the cupola for making single large castings beyond the melting capacity of the normal equipment. We have made castings in phosphor bronze weighing up to 25,000 lb. by this method with excellent results. Where only occasional heats are made, and conditions may vary, it is not practical to accumulate enough data on melting loss to permit the use of alloy ingot. Good metal can be made by melting the copper in the cupola, using normal grades of cupola coke and normal iron foundry bed and blast conditions. One 36-in. cupola in use is operated with a 1500-lb. bed and 150 lb. of coke to each 1000-lb. charge of copper, with a 500-lb. cover on the last charge. All of the tin, lead and zinc should be added to the ladle in this case. Sulphur pick-up, which has been a source of concern to many foundries, has been in the order of 0.03 per cent. Physical properties have been excellent. Navy "G" bars from cupola heats have averaged about 50,000 psi. ultimate strength, and 65 per cent elongation, while heats of Navy "M" had properties averaging 40,100 psi. ultimate strength and 41 per cent elongation.

I hope that Mr. Long will find it possible to publish additional data in the near future.

R. H. COWEN<sup>2</sup>: We have operated a Schwartz furnace and I believe that the operation, as far as zinc losses are concerned, is rather similar to that reported by Mr. Long. We have found, over a period of time, that the zinc loss is quite a factor, in which time and temperature control are very vital. In continuous operation, with critical time and temperature control factors, how would you care for the zinc loss in order to maintain a constant amount of zinc in your metal through the day?

<sup>1</sup> Allis-Chalmers Mfg. Co., Milwaukee, Wisc.

<sup>2</sup> Columbian Bronze Corp., Freeport, N. Y.

MR. LONG: We were not concerned greatly with zinc loss because the highest zinc content we were melting was 4 per cent. The zinc loss due to non-uniform operation will not fluctuate with that amount.

MR. COWEN: What is the average operating temperature of the cupola throughout the day?

MR. LONG: In the melting zone? Of course, we are never able to measure it but I would think it to be in the neighborhood of 3500 to 4000° F.

MR. COWEN: Your zinc loss would be terrific.

MR. LONG: Yes.

HAROLD J. ROAST<sup>3</sup>: Mr. Higgins reported a method in which the copper is melted in the cupola and all additions are made in the ladle. That seems to me to be an ideal way of obtaining uniformity of product if it can be used at all times. Mr. Long, is it practical to obtain a uniform product by using gates or ingots in the charge and, if so, is there some special way in which you go about it?

Also, what is your opinion of the cupola for silicon bronze? My experience has been with reverbratory furnaces of 30,000-lb. capacity, but I suspect that silicon bronze would go very readily or satisfactorily into a cupola.

MR. LONG: We have no difficulty with uniformity. We varied the percentage of the mixture in the charge. We could use all gates or all borings or all ingot. We have had very accurate laboratory control and, as far as uniformity is concerned, that was not a problem. Certainly, melting copper and adding the low melting point ingredients to the ladle is ideal. Of course, you must get that copper out of the tap hole at 2500 to 2600° F. in order to take care of additions of 20 to 25 per cent. You can heat the tin and lead additions and it will help some. But, by the time you get metal tapped into the ladle under those conditions, you have to bring it from the tap hole above 2400° F. You can not use the stock back again. You can not charge prealloyed material and copper because there is a difference of 200° F. in melting temperature and the copper will lay back.

As far as melting silicon bronze is concerned, we have never melted any, but I am fairly certain it would be satisfactory.

F. P. ULEZELSKI<sup>4</sup>: Have any attempts been made to inject any of the alloys, such as zinc or lead, into the basin of the cupola after the copper is melted down and before tapping?

MR. LONG: In other words, put them in below the tuyeres, have them alloyed at that point.

MR. ULEZELSKI: That is right. By tapping out into the ladle you are sure to get a good alloy, better than by ladle addition, I believe.

MR. LONG: The flow of metal from the tap hole will give a greater mixing effect than in the basin of the furnace.

MR. ULEZELSKI: We would have the combined action, the flow from the cupola and down into the ladle.

MR. LONG: How would you get it completely mixed? There is metal continually coming down.

MR. ULEZELSKI: By stopping the blast to drain the cupola.

MR. LONG: It would be hard to hold an analysis that way.

MR. ULEZELSKI: You would be able to judge that by the time element.

<sup>3</sup> Canadian Bronze Co., Montreal, P. Q., Canada.

<sup>4</sup> Ampco Metal, Inc., Milwaukee, Wisc.

MR. LONG: I have no doubt it could be worked out all right but I see no advantage.

MEMBER: How do you maintain temperature control and what would be the minimum practical cupola operation for the small foundry as against a crucible furnace?

MR. LONG: Temperature control is maintained by the height of the bed and, of course, constant charging, constant air. When the melting rate falls below 2500 lb. per hr., the operation is inefficient and it becomes a problem to keep up a continuous supply of metal. You may require 2500 lb. of metal one hr., and then you may want to jump to 4000 or 6000 lb. the next hour. When you get down to 2500 lb. the furnace cools down and then you can not bring it back fast. During the depression days we used furnaces that probably did not produce better than a ton an hr. average, but it was not good melting.

MEMBER: Judging by the losses shown in the paper, it would appear to me as though the cupola would not be profitable for brass melting. And then, with the shortage of zinc and lead, would we be permitted to melt in the cupola?

MR. LONG: When lead and zinc losses, zinc being of the order of 5 per cent, are weighed against the extremely low melting cost and the high-speed production obtained, cupola melting is an economical operation.

B. A. MILLER<sup>2</sup>: Mr. Long, you spoke of temperatures of around 3500° F. in the melting zone. To my mind, that is questionable.

With reference to the melting of silicon bronze in the cupola, those of us who have operated cupolas readily appreciate that there is a 10 per cent silicon loss in the manufacture of gray iron in the cupola. In melting silicon bronze, would you expect part of the silicon to oxidize? I am thinking about the 20 to 1 ratio of which you speak.

MR. LONG: Yes, I would expect to lose silicon in much the same way we lose lead. I would venture to say that the silicon loss probably would be 50 per cent of the content.

MR. MILLER: Mr. Roast, would you put that back?

MR. ROAST: In the first place, I said I had not melted silicon bronze in a cupola, I have never had to put it back. In operating a 30,000-lb. reverbratory furnace, we should have an opportunity for oxidation and we do not have to provide twice as much silicon as we expect to get in the final product.

MR. MILLER: It would be my thought that with a 20 to 1 coke ratio you would be very close to the oxidizing side of the cupola because the average cast iron practice is 10 to 1 coke ratio and sometimes drops as low as 6 to 1. Therefore, it seems to me that melting silicon bronze in a cupola would be conducive to very high silicon loss.

MR. LONG: I am quite sure that the silicon losses are going to be high because back in the earlier days, when we had the smaller diameter furnace, we used to get it extremely hot at times and lay it over, and we got metal with all appearances of having aluminum in it, a silvery sheen, which we later found to be silicon. It came from the silicon-carbide lining.

We also have found in past years, like everyone else, that we would buy a carload of scrap, melt it, and find aluminum in the metal. We found, by passing that ingot back through the same furnace, that we would get rid of the aluminum and silicon. I am rather sure that you would lose quite a lot of silicon.

MR. MILLER: Possibly with that setup you could do the same thing that the cast iron people do, make inoculations at the spout.

MR. LONG: Yes, in that respect the furnace lends itself to a further research on either filtering the metal at the spout or treating it with oxidizing slags or reducing slags, or under-pouring, and etc.

<sup>2</sup> Baldwin Locomotive Works, Cramp Brass & Iron Foundries Div., Philadelphia, Pa.

# Considerations in Casting and Coining Malleable Iron

By H. W. STREETER\*, DECATUR, ILL.

## Abstract

*The author discusses the process of coining to produce malleable iron castings having a dimensional accuracy equal to that of machined surfaces. By coining, the author refers to the application of pressure to opposite surfaces of a casting to control the dimension between the pressed surfaces. The author states that the data is insufficient to warrant drawing many conclusions, but by presenting the data, he hopes to stimulate further research and reporting on the coining process.*

## INTRODUCTION

1. At the outset, it should be stated that the title of this paper has been kicked around a bit by those of us responsible for it. We had hoped to present some accurate statements on the science of coining malleable iron, particularly with respect to tolerances obtainable, and to point with pride to the machining operations which can be eliminated by coining, if it is properly controlled. As our investigation proceeded, however, we encountered many side-tracks which have been titled "Considerations." These are presented with the hope that others will pursue them to conclusions, something not to be found in this discussion.

2. Coining, as we know it, is the act of applying pressure to opposite surfaces of a malleable iron casting for the purpose of controlling a dimension—usually the thickness of the metal—between the pressed surfaces. Many properties of malleable iron are affected by this operation. As we change the dimensions of a casting by pressure, we likewise affect its tensile strength, compressive strength, elongation, hardness, density, resistance to wear, and all other properties associated with these. The operation is essentially cold-flowing by compression.

3. It was desired to learn something of the degree of dimensional and physical changes caused by the application of pressure and some experiments were conducted for this purpose.

4. A number of malleable castings were made, consisting of two sets of flat rings. All were  $2\frac{1}{2}$ -in. in diameter with a 1-in. central core. One set was

\* Wagner Malleable Iron Co.

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approximately  $\frac{1}{2}$ -in. thick and one set was approximately 1-in. thick. This paper will not attempt to report in detail on the variable results found in casting and coining all these combinations. However, certain definite trends of the behavior of malleable iron upon casting and under pressure were observed and these are reported.

#### VARIATIONS IN CONTRACTION

5. Inasmuch as dimensional change was a prime consideration in this investigation, contraction from pattern size was accurately determined.

6. Patterns for rings described were machined from aluminum and mounted and gated on a machined aluminum plate. Castings were made by a regular squeezer molder under conditions of facing, sand, molding method, and pouring identical to those prevailing in daily production. The metal poured was cupola-air-furnace duplex iron of the composition carbon—2.41; silicon—1.18. Castings were annealed and cleaned by wheelabrator and, in some cases, minor roughness was removed by filing. The results on a  $\frac{1}{2}$ -in. group were as follows:

Pattern thickness .....	.505 in.
Average thickness of casting .....	.517 in. (18 readings)
Average thickness range .....	.510-.524 (0.14) in.
Maximum variation/piece .....	.009 in.
Minimum variation/piece .....	.004 in.

7. At this point, it was observed that castings failed to contract as expected. The use of an eighth inch shrink rule in preparing malleable patterns contemplates an initial contraction of  $\frac{1}{4}$ -in. per ft., followed by an expansion in anneal of  $\frac{1}{8}$ -in. per ft. Corresponding allowance was made in pattern thickness at .505-in. Malleable castings should theoretically check .500-in. Actual results showed .517-in. A re-test was made on group two at 1-in. thickness and these results were confirmed.

8. While it is not stated that the castings failed to contract, it is observed that due to swell or some other phenomenon not explained, the final iron thickness was greater than the pattern thickness. Thickness is a vertical mold dimension not affected by draft or vibration in drawing.

#### COINING FOR ACCURACY

9. We took our samples to the press, and point out that in 18 specimens we had an average thickness of .517-in. with an over all variation of .510-in. to .524-in. or .014-in. We compressed the average  $\frac{1}{32}$ -in. For this purpose die stops were made at .485-in. thickness. These stops were used to separate under pressure two hardened and ground steel plates which we called "flat-ters." Plates were checked for alignment in the press and their planes were parallel within .003-in. dial indicator reading. Pressure was gradually built

up to 300 tons and released automatically without dwell or holding interval at maximum pressure. The results were as follows:

Die stops .....	.485 in.
Average thickness after pressing .....	.493 in. (18 readings)
Range of thickness .....	.488-.495 (.007) in.
Maximum Variation/piece .....	.005 in.
Minimum Variation/piece .....	.002 in.

10. *Observations.* Still mindful that we are speaking in averages, note that the metal showed a "spring-back" of .008-in. over minimum deformation of thickness, and took a "permanent set" at .024-in. under the original thickness. In this operation the metal is elastic with an index of .008 and it is also plastic with an index of .024. Upon release of stress in this test, the castings regained 25 per cent and retained 75 per cent of the total deformation. The elasticity of malleable iron accounts for the ever-present difficulty in properly straightening the product.

11. Note the range of variation was effectively reduced—.014 to .007-in. It should be stated in addition that 16 out of 18 castings showed variation of .004-in. or less. (All micrometer readings were made on each piece in 3 places, left and right of gate and opposite gate.)

12. The same castings were then repressed at 400 tons with the following results:

Die stops .....	.452 in.
Average thickness .....	.462 in. (18 readings)
Range thickness .....	.459-.464 (.005) in.
Maximum Variation/piece .....	.005 in.
Minimum Variation/piece .....	.002 in.

Ten castings showed variation of .003-in. or less, and eight castings showed .004-in. and .005-in.

13. Twelve of these coined castings were stacked on a surface plate and a dial indicator reading over the surface of the top castings showed a variation of .004-in. Castings were then rotated in the stack and the total variation in height of the stack did not vary more than .004-in. on any reading.

14. Our practice in coining for thickness control is to allow approximately 1/32-in. metal over desired size. If, for example, it is desired commercially to coin a casting to .500-in. plus or minus .008-in., this procedure would be followed: The pattern would be made .520 to .530-in., using a standard rule. Castings would be expected to check .530 to .540-in. Stops would be made to low limit of .492-in. and coined castings should check .500-in. plus or minus .008-in. Important factors to be dealt with are absence of contraction upon casting, and expansion or spring-back after pressing. Design of casting influences these allowances. Any similarity of this sample to existing castings is purely coincidental.

## EFFECT OF PRESSURE

15. It was desirable to learn what effect coining has on the physical properties of malleable iron. For this purpose the standard A.S.T.M. test bar was duplicated, except that the  $\frac{5}{8}$ -in. round section was changed to a .555-in. square section, the respective areas being equal. Three sets of bars were cast. They were pressed in varying degrees on specially constructed dies on the 2-in. flat dimension. Results recorded were as follows:

	<i>Tensile</i> <i>Strength</i>	<i>Elongation</i>	<i>Brinell</i> <i>Hardness</i>	<i>Specific</i> <i>Gravity</i>
<i>Series One (2.41 Carbon)</i>				
A—As cast	53500	13%	137	
B—Reduced .025-in.	59750	4%	163	
C—Reduced .063-in.	60500	2%	179	
<i>Series Two (2.56 Carbon)</i>				
A—As cast	51400	11%	139	7.15
B—Reduced .040-in.	58600	3%	163	7.30
C—Reduced .060-in.	60500	3%	170	7.30
<i>Series Three (2.45 Carbon)</i>				
Round Bar	56600	19%	143	
A—As cast	52200	10%	143	7.27
B—Reduced .015-in.	54800	5%	149	7.32
C—Reduced .040-in.	59200	4%	163	7.40
D—Reduced .076-in.	53600	0%	179	7.40

16. *Observations.* Upon comparison of elongations determined by the standard round bar, the values recorded from the square bar were lower for the same metal. In this connection the nature of this test should be kept in mind. Upon pressing, the 2-in. dimension was elongated by compression and the value reported under elongation is the percentage of additional elongation under tension.

17. Malleable iron work hardens under pressure. After pressure it appears to react as if heat-treated. Tensile strength increases, hardness increases, elongation drops. If resistance to wear varies with hardness, then it can be assumed that this quality of the metal has been improved by pressing or coining.

18. With increase in pressure, these properties continue to vary, each in proportion. Due to limitations of the simple test made, maxima of each property could not be determined. It should be stated that one bar not recorded here and reduced .200-in. in thickness showed a Brinell hardness number of 207.

19. An interesting supplementary test was made. A standard test bar was hammered on the 2-in. test length on an anvil, and pulled and compared with a companion bar not so treated. The tensile strength was increased from 52,000 to 58,000 psi. and elongation dropped from 14 per cent to 4 per cent.

20. Let us remember, also, that while some malleable castings are affected

in 100 per cent of their metal by coining, others are only coined over a small portion of their total metal. Therefore, the changes in properties which accompany this operation may or may not be important in the use of the casting.

21. One definite fact remains. That is, coining is a simple and fast method of finishing two opposite sides of a casting with accuracy equal to milling or cutting and, we believe, superior to disk-grinding. Coining suggests a quality of malleable iron which, if exploited, will give this product a new competitive advantage over other ferrous products.

# The Effect of Copper on the Properties of Cast Carbon-Molybdenum Steels

By N. A. ZIEGLER\* AND W. L. MEINHART\*, CHICAGO, ILL.

## Abstract

*Numerous investigations of the effects of copper on the properties of various steels have been reported, most of the work being done with wrought steels. The authors present the results of studies of the effects of copper on the physical properties of carbon-molybdenum cast steels. Data obtained from the studies are shown in graphic and tabular form. An extensive bibliography attests the scope of the investigation.*

## INTRODUCTION

1. The effects of copper on the properties of various steels have been studied by many investigators and reported in numerous books and technical articles (see bibliography). Perhaps the most thorough summary of this subject was made by Gregg and Daniloff<sup>1</sup> and by Cornelius<sup>2</sup>. One of the claims of the beneficial effect of copper is the improvement in the resistance of the resultant steels to certain types of corrosive environments<sup>3-14</sup>. The other claim is the strengthening effect which copper exerts upon steel<sup>15-59</sup>.

2. It is also known that copper-bearing steels can be age-hardened by low temperature drawing after quenching or normalizing<sup>60-70</sup>. The latter phenomenon is due to certain peculiarities in the iron-copper constitutional diagram. These two metals form a eutectoid at 810 to 850° C. (1490 to 1560° F.). At that temperature, alpha iron can hold over 1 per cent copper in solid solution. (According to Buchholtz and Koster<sup>61</sup>, this solid solubility of copper in iron is over 3 per cent). At room temperature, the solid solubility decreases to less than 0.5 per cent. Therefore, hardness of a copper-bearing steel, which is composed of a super-saturated solution of copper in alpha-iron, can be increased by aging at some temperature under 800° C. (1470° F.). This phenomenon is due to precipitation of the copper-rich phase.

3. The bibliography at the end of this paper is a testimony of considerable

\*Research Metallurgist and Ass't. Research Metallurgist, respectively, Research and Development Laboratories, Crane Co.

<sup>1</sup>Superior numbers refer to bibliography at the end of this paper.

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work done and information accumulated on copper-bearing steels. Any additional general remarks on the nature of these alloys thus appear to be unnecessary.

4. Most of the work done so far has been with wrought steels, and relatively little information is available on cast and heat treated steels.

5. One of the common steels used for making castings for high temperature superheated steam service is carbon-molybdenum steel of the nominal composition, shown in Table 1. The specifications for its physical properties are as shown in Table 2. In order to meet these physical properties with the usual heat treatment, the carbon content of this steel has to be adjusted to about 0.25 per cent. The molybdenum content of about 0.5 per cent imparts creep resistance at elevated temperatures. The maximum operating temperature of 950° F. (510° C.) with corresponding pressures is recommended.

### *Weldability*

6. Even though this steel is designated as "weldable" and is used in various welded installations, its welding quality is not as good as that of plain carbon steels of the same carbon content, because of the presence of molybdenum, which increases thermal sluggishness of the metal, thus making it more hardenable.

7. In general, the weldability of a steel is improved in proportion to the decrease of (1) its carbon content, and (2) its alloying elements. In this particular case, the percentage of molybdenum is fixed by the requirement of high temperature creep resistance. By decreasing the carbon content, weldability of the steel is improved, but its tensile strength and yield point values are lowered below those specified. The problem thus was, to reduce the carbon, thus improving the weldability, and to introduce some alloying element which will develop the desired physical properties. The alloying element should be selected so that its detrimental effect on weldability would be at a minimum.

8. On the strength of previously existing knowledge and some of our own preliminary experiments, it could be expected that copper in amounts of 0.5 to 1.5 per cent would be a promising ingredient in this case.

9. Therefore, it was decided to thoroughly investigate the entire field of low carbon-molybdenum copper-bearing steels. This paper presents a summary of the results of the research.

### EXPERIMENTAL PROCEDURE

10. A series of copper-bearing, carbon-molybdenum steels was prepared in a 200-lb. basic-lined high-frequency induction furnace, using low carbon steel scrap as raw material and conventional melting and deoxidizing technique. Each heat was killed by an addition of about 2.5 lb. of aluminum per ton, tapped into a 250-lb. capacity ladle, and cast into keel coupon blocks,



Table 1

## CARBON-MOLYBDENUM STEEL COMPOSITION

<i>Element *</i>	<i>Per Cent</i>
Silicon .....	0.20-0.45
Manganese .....	0.50-0.70
Sulphur .....	0.06 (max.)
Phosphorus .....	0.05 (max.)
Carbon .....	0.15-0.30
Molybdenum .....	0.40-0.60

Table 2

## CARBON-MOLYBDENUM STEEL—PHYSICAL PROPERTIES

<i>Properties</i>	
Tensile Strength, psi.....	70,000 (min.)
Yield Point, psi.....	45,000 (min.)
Elongation, per cent.....	22 (min.)
Reduction of Area, per cent.....	35 (min.)
Charpy Impact Resistance, ft. lb. (70° F.)..	25 (min.)
Brinell Hardness Number.....	165 (max.)

using green sand molds. Later on, some of the heats were duplicated, and cast into coupon blocks and 2-in. special flanged "tees" (Fig. 1). Each coupon block was sectioned into convenient blanks and heat treated by normalizing from 1750 to 1800° F. (950 to 980° C.)

11. The blanks from each coupon were divided into three groups, one of which was drawn for 2 hr. at 1000° F. (540° C.), another at 1150° F. (620° C.), and the last at 1300° F. (700° C.). Blanks thus treated were subjected to tensile\*, Brinell hardness, and Charpy impact testing\*\*. The latter test was performed at (1) room temperature and (2) -25° F. (-31° C.). Most of the compositions were also subjected to thermal analysis, using a dilatometer. Welding tests were made on all experimental castings (tees) after they had been heat treated by normalizing from 1750 to 1800° F. (958 to 980° C.) and drawing at 1150° F. (620° C.). Test data thus accumulated (with the exception of welding tests) are presented in Table 3, together with the chemical analysis of each heat.

12. It may be noted that all compositions may be divided into two main groups, those containing 0.1 per cent carbon, and those containing 0.2 per cent carbon. Each group, in turn, may be subdivided into three sub-groups, (1) molybdenum-free steels (introduced here for general comparison), (2) those containing 0.5 per cent molybdenum, and (3) those containing 1.0 per cent molybdenum. The two latter sub-groups are composed of steels containing (1) zero per cent copper, (2) 0.5 per cent copper, (3) 1.0 per cent copper, and (4) 1.5 per cent copper. Compositions containing 0.5 per cent molybdenum with 0.5 and 1.0 per cent copper appeared to be of

\*Standard 0.505-in. diam., 2-in. gauge test bar.

\*\*Standard Charpy test bar with a keyhole notch.

particular interest, so several additional check heats of each were cast, heat treated and tested. Figures representing physical data were averaged from at least two or more tests\*.

13. The contents of silicon, sulphur and phosphorus (Table 3) are reasonably uniform in all steels. The manganese content varies within rather wide limits. This resulted from attempts to study the effect of manganese in parallel with that of copper. This element in the amounts used was found to be relatively ineffective, as compared to copper, and therefore has only a slight influence on the physical properties reported. In two instances (nos. 8 and 16) the content of chromium happened to be rather high, probably because of contamination from the furnace lining.

#### THERMAL ANALYSIS AND MICROEXAMINATION

14. Most of the compositions presented in Table 3 were subjected to thermal analysis by means of a differential dilatometer. This instrument is so arranged that a thermal expansion-contraction curve is automatically recorded on a photographic film. In each case, a specimen (50 millimeters long and 4 millimeters in diameter) was heated to about  $1000^{\circ}\text{C}$ . ( $1830^{\circ}\text{F}$ .) in 2 hours, and then cooled to room temperature at an average rate of  $50^{\circ}\text{C}$ . ( $90^{\circ}\text{F}$ .) per minute.

15. Figures 2 and 3 are reproductions of representative curves for steels containing 0.1 and 0.2 per cent carbon, respectively. In each case, the upper curve includes the heating and cooling branches. In view of the fact that the heating branches for all these steels are practically identical, they have

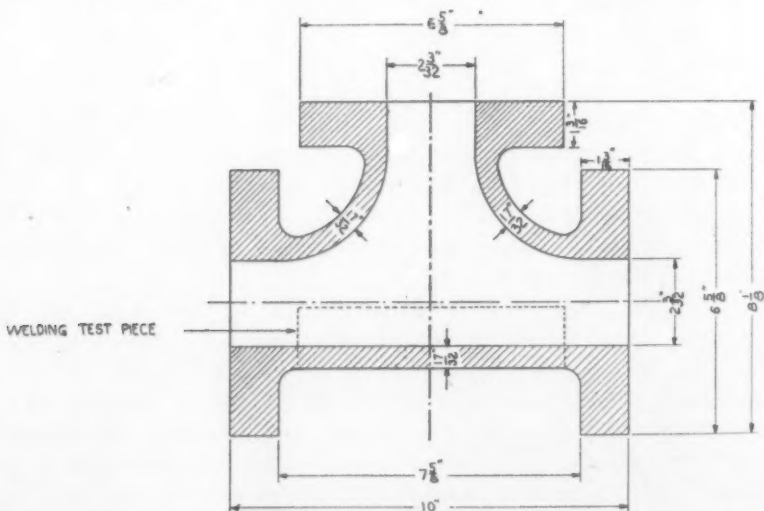


FIG. 1—SECTIONAL VIEW OF 2-IN. SPECIAL FLANGED "TEE" EXPERIMENTAL CASTING (PATTERN DIMENSION).

\*Variations in test results represented by each average figure came within normal limits of experimental error.

## CHEMICAL ANAL

SERIAL NO.	NOMINAL COMP.			CHEMICAL ANALYSIS								DILATOMETER DATA				DRAWN AT 1000 F									
	C	MO	CU	SI	MN	S	P	C	MO	CU	CR	5 HR COOL		AIR COOL		TENSILE PROPERTIES									
												RUN NO.	VPN	RUN NO.	VPN	TS F <sub>el</sub>	YP PSI	PL PSI	BS PSI	EL. %	R.A. %	M.E. PSI x10 <sup>6</sup>	Y.R.		
1	0.1	0	0	0.28	0.27	0.022	0.015	0.10				459	104	460	112	54,900	39,700	34,800	125,400	42.5	71.8	30.5	0.60		
2	0.1	0	0.5	0.28	0.35	0.016	0.017	0.12		0.68		456	114	455	124	60,000	38,000	39,800	127,000	41.5	67.3	29.2	0.62		
3	0.1	0.5	0	0.28	0.97			0.10	0.70							59,900	28,300	18,300	126,300	39.0	70.5	28.9	0.47		
4	0.1	0.5	0.5	0.30	0.26	0.028	0.016	0.08	0.57	0.62		461	124	462	138	63,500	39,900	41,600	133,000	38.5	67.8	28.0	0.63		
5	0.1	0.5	0.5	0.30	0.31	0.026	0.018	0.09	0.52	0.58	0.03	890	127	891	138	56,900	28,300	22,600	132,200	32.2	56.5	30.0	0.50		
6	0.1	0.5	0.5	0.33	0.58	0.030	0.020	0.10	0.54	0.58	0.03	893	131	892	151	62,400	35,300	28,800	115,500	35.5	61.5	32.0	0.56		
7	0.1	0.5	1.0	0.33	0.20	0.029	0.015	0.08	0.49	1.11		463	159	464	138	85,570	66,100	66,300	171,000	29.0	63.4	30.2	0.77		
8	0.1	0.5	1.0	0.32	1.04	0.024	0.018	0.06	0.49	1.06	0.22	504	169	503	222	97,900	69,000	39,500	143,000	23.0	45.0	26.7	0.71		
9	0.1	0.5	1.0	0.34	0.33	0.031	0.018	0.08	0.48	1.05	0.05	894	158	895	151	87,100	64,900	51,000	117,100	21.5	45.5	34.8	0.75		
10	0.1	0.5	1.0	0.23	0.52	0.030	0.020	0.09	0.53	1.07	0.03	897	176	896	161	88,000	66,500	61,800	142,600	26.0	51.3	31.8	0.75		
11	0.1	0.5	1.5	0.30	0.27	0.026	0.014	0.12	0.54	1.63		494	191	493	210	99,600	77,700	62,900	133,200	23.0	50.0	30.2	0.78		
12	0.1	1.0	0	0.35	0.94			0.11	1.02							70,600	41,600	28,100	127,000	31.4	64.8	29.1	0.59		
13	0.1	1.0	0.5	0.34	0.18	0.034	0.018	0.09	1.04	0.58		492	132	491	138										
14	0.1	1.0	1.0	0.29	0.47			0.10	1.05	0.91	0.07	496	151	495	201	94,700	66,300	43,400	141,700	25.0	47.3	29.5	0.70		
15	0.1	1.0	1.5	0.42	1.14	0.026	0.018	0.11	1.09	1.65	0.05	610	236	611	272	129,000	87,700	45,800	171,700	17.5	35.8	29.8	0.68		
16	0.2	0	0	0.33	1.04			0.17	0.02	0.15	0.38	498	139	497	150	74,500	48,100	47,900	131,300	35.2	58.3	30.3	0.65		
17	0.2	0	0.5	0.42	0.94	0.024	0.017	0.13	0.02	0.55	0.02	508	136	507	143	69,400	43,000	38,000	124,100	36.0	58.5	28.8	0.62		
18	0.2	0.5	0	0.33	0.75	0.032	0.020	0.13	0.52		0.03														
19	0.2	0.5	0	0.43	0.80			0.22	0.57							74,600	37,900	25,900	124,500	30.8	55.4	29.6	0.51		
20	0.2	0.5	0.5	0.36	1.54	0.026	0.017	0.21	0.52	0.54	0.05	504	169	503	222	88,700	53,100	28,200	141,400	26.5	49.0	28.6	0.60		
21	0.2	0.5	0.5	0.26	0.38	0.025	0.016	0.18	0.52	0.59	0.06	913	155	914	167	73,600	42,400	39,700	126,400	30.0	53.8	30.5	0.58		
22	0.2	0.5	0.5	0.29	0.52	0.037	0.019	0.19	0.54	0.58	0.09	898	159	899	178	75,900	46,400	42,900	125,000	29.3	50.5	32.0	0.61		
23	0.2	0.5	1.0	0.41	0.90	0.025	0.022	0.17	0.55	1.04	0.02	577	196	576	230	101,600	73,000	45,000	141,400	19.5	34.0	31.9	0.72		
24	0.2	0.5	1.0	0.46	0.78	0.033	0.021	0.20	0.54	0.79	0.01	908	180	907	202	89,300	59,100	44,100	111,400	16.8	45.5	30.8	0.65		
25	0.2	0.5	1.0	0.37	0.48	0.017	0.020	0.18	0.55	1.04	0.34	909	191	910	190	95,000	74,100	61,900	154,900	24.0	49.0	33.0	0.78		
26	0.2	0.5	1.0	0.42	0.67	0.027	0.022	0.17	0.52	1.01	0.23	912	200	911	214	105,900	81,600	59,800	144,000	17.5	41.0	31.0	0.77		
27	0.2	0.5	1.5	0.39	0.95	0.023	0.022	0.18	0.55	1.50	0.02	579	225	578	249	108,800	82,300	47,000	157,300	19.0	40.0	29.4	0.76		
28	0.2	1.0	0	0.38	0.74			0.22	0.97							84,200	46,900	32,400	150,300	27.8	55.8	29.4	0.56		
29	0.2	1.0	0.5	0.42	1.02	0.025		0.19	0.98	0.45	0.02	533	191	534	263	97,700	64,300	40,400	150,500	21.0	44.5	31.0	0.66		
30	0.2	1.0	1.0	0.40	0.96	0.023	0.022	0.20	1.08	1.09	0.01	615	225	614	279	114,300	79,200	43,500	149,300	18.5	32.3	27.5	0.70		
31	0.2	1.0	1.5	0.38	0.92	0.028	0.022	0.18	1.00	1.57	0.03	616	235	617	281	127,000	90,800	47,100	173,800	19.0	40.0	28.8	0.72		

\*MANGANESE UNDER 0.5%.

\*\*MANGANESE OVER 0.5%.

Ø HEATS FROM WHICH EXPERIMENTAL CASTINGS WERE MADE, AND SUBJECTED TO WELDING TEST.

Ø CHROMIUM OVER 0.1%.

TABLE 3

CHEMICAL ANALYSES AND PHYSICAL PROPERTIES OF COPPER BEARING STEELS, NORMALIZED AT 1750 - 1800 F  
(PHYSICAL DATA FIGURES ARE AVERAGE VALUES OF TWO OR MORE TESTS.)

DRAWN AT 1150 F																				
			HARD. BHN	CHARPY IMPACT RESIST.		TENSILE PROPERTIES										HARD. BHN	CHARPY IMPACT RESIST.			
R.A. %	M.E. PSI X10 <sup>6</sup>	Y.R.		FT RT	LBS -25F	TS PSI	YP PSI	PL PSI	BS PSI	EL. %	R.A. %	M.E. PSI X10 <sup>6</sup>	Y.R.	FT RT	LBS -25F		TS PSI	YP PSI		
71.8	30.5	0.60	116	46.5	30.5	55,400	32,400	33,500	126,000	42.5	71.0	26.3	0.59	117	46.5	32.5	56,000	33,800		
67.3	29.2	0.62	129	37.5	25.3	59,200	37,500	32,800	131,200	39.0	67.0	30.8	0.63	126	36.8	27.0	60,900	39,000		
70.5	28.9	0.47	144			60,110	27,800	24,500	118,000	39.2	69.0	29.5	0.46	152			59,100	39,800		
67.8	28.0	0.63	142	34.5	24.8	61,800	39,800	42,200	133,000	39.5	69.5	31.0	0.64	145	41.5	30.0	64,300	29,600		
56.5	30.0	0.50	134	37.5	26.5	58,700	31,900	29,700	115,300	35.6	62.0	32.0	0.54	130	31.4	24.3	59,700	30,100		
61.5	32.0	0.56	140	39.0	24.8	63,400	38,000	36,200	129,200	35.5	65.3	35.6	0.60	138	31.5	28.2	61,300	34,900		
63.4	30.2	0.77	202	22.5	3.3	76,200	50,500	52,300	152,800	32.5	71.3	29.0	0.66	158	39.5	27.3	64,700	32,300		
45.0	26.7	0.71	227	21.5	2.5	74,900	50,000	39,300	148,400	30.0	58.5	28.4	0.67	173	25.0	20.0	89,800	45,900		
45.5	34.8	0.75	206	18.5	6.5	76,900	56,100	44,700	132,000	25.9	55.8	33.0	0.73	185	32.0	21.5	63,600	41,700		
51.3	31.8	0.75	209	21.5	6.8	82,300	62,300	57,500	143,000	27.0	59.0	33.5	0.76	180	28.8	20.0	63,600	43,300		
50.0	30.2	0.78	227	18.0	10.0	93,600	64,800	58,000	151,700	29.5	59.5	29.3	0.69	173	23.0	20.0	81,200	68,800		
64.8	29.1	0.59	168			67,400	32,600	22,400	111,000	33.8	63.7	28.8	0.48	148			64,700	34,700		
				34.3	22.8	62,000	39,500	38,000	114,700	28.0	53.0	27.2	0.64	138	37.3	29.0	64,800	28,700		
47.3	29.5	0.70	220	20.0	7.3	76,400	57,100	41,600	139,000	29.0	59.3	29.6	0.75	178	29.0	18.3	82,300	38,100		
35.8	29.8	0.68	288	8.0	3.3	98,800	70,500	43,500	149,300	18.0	49.0	26.3	0.71	220	18.5	5.3	110,700	59,100		
58.3	30.3	0.65	153	34.3	25.0	72,400	43,500	43,300	135,400	36.0	59.0	32.0	0.60	149	34.5	21.0	77,100	44,600		
58.5	28.8	0.62	146	37.0	28.5	67,400	41,100	41,200	131,300	36.3	63.5	29.1	0.61	143	34.0	23.0	72,700	42,300		
						66,100	41,500	41,000	130,000	35.8	61.0	30.0	0.63	136			63,900	39,300		
55.4	29.6	0.51	165			74,100	43,500	29,200	140,300	32.6	60.0	29.7	0.59	167			73,700	42,100		
49.0	28.6	0.60	200	27.0	15.3	81,000	55,500	50,000	140,000	27.0	55.0	29.3	0.69	180	29.0	15.0	114,500	58,200		
53.8	30.5	0.58	162	27.3	19.5	73,100	43,600	42,600	140,500	29.1	49.7	32.9	0.60	158	30.3	22.3	90,900	54,200		
50.5	32.0	0.61	164	26.3	16.5	74,500	47,500	48,200	145,500	27.9	51.2	31.7	0.64	164	24.3	16.2	90,700	55,600		
34.0	31.9	0.72	236	16.3	6.3	81,400	56,100	39,100	144,600	26.5	51.5	29.3	0.69	178	22.8	14.5	110,000	54,800		
45.5	30.8	0.65	200	14.3	6.8	85,800	56,900	45,900	142,900	19.4	50.8	30.1	0.66	179	23.5	16.3	80,700	54,300		
49.0	33.0	0.78	237	15.8	5.8	86,200	63,200	60,300	140,000	22.4	45.7	32.6	0.73	200	23.0	11.1	103,600	50,800		
41.0	31.0	0.77	250	9.5	2.3	93,500	71,500	56,700	129,800	18.4	41.3	31.5	0.77	226	25.6	14.0	101,500	58,000		
40.0	29.4	0.76	247	12.0	5.0	90,400	73,100	38,800	147,400	25.3	50.8	29.0	0.81	210	23.0	14.8	118,400	58,500		
55.8	29.4	0.56	193			85,900	51,300	36,700	146,500	27.8	52.3	30.3	0.60	196			83,200	48,500		
44.5	31.0	0.66	228	16.5	10.3	87,400	57,400	55,800	156,700	26.5	57.5	27.6	0.66	194	29.5	19.5	118,400	56,700		
32.3	27.5	0.70	260	11.8	4.0	117,800	73,700	47,000	162,600	22.7	52.5	29.5	0.64	210	26.8	20.0	123,400	62,300		
40.0	28.8	0.72	270	11.5	4.8	125,200	81,600	62,600	175,500	20.0	52.5	30.2	0.65	240	25.3	16.0	121,100	63,200		



DRAWN AT 1300 F

TENSILE PROPERTIES							HARD. BHN	CHARPY IMPACT RESIST.		
PL PSI	BS PSI	EL. %	R. A. %	M. E. PSI X10 <sup>6</sup>	Y. R.	FT		LBS		
						RT		-25F		
35,800	35,700	133,300	42.0	72.3	32.3	0.60	140	48.5	29.0	*
40,000	43,900	133,800	38.0	66.0	30.6	0.64	142	43.0	28.3	*
42,800	24,300	132,000	39.9	73.1	29.5	0.67	148			**
42,600	21,000	138,500	36.5	67.8	30.3	0.46	144	39.3	26.3	*
40,100	25,700	122,000	34.5	64.5	30.5	0.50	132	35.8	27.0	* Ø
41,900	39,100	122,800	37.0	65.5	33.5	0.57	135	34.2	27.5	** Ø
42,300	23,300	142,700	36.5	69.0	29.3	0.50	152	38.0	27.5	*
45,900	23,300	142,500	26.0	55.2	28.7	0.51	210	33.0	20.0	** Ø
41,700	40,200	120,000	35.0	63.0	30.5	0.65	143	40.5	29.8	* Ø
43,300	43,800	130,600	35.7	66.5	31.8	0.68	145	32.5	28.0	** Ø
42,800	38,300	149,300	28.3	46.3	31.7	0.85	178	20.8	14.3	*
41,700	20,500	113,000	30.7	62.1	28.4	0.52	163			**
42,700	19,200	134,000	36.5	67.0	30.0	0.44	146	36.8	35.0	*
42,100	17,800	136,900	27.0	50.0	28.1	0.46	184	19.5	8.3	*
42,100	25,000	174,800	23.0	43.5	28.0	0.53	274	16.0	6.5	**
42,600	36,000	125,700	32.0	61.0	28.0	0.58	168	31.3	22.8	** Ø
42,300	39,400	169,500	34.0	66.0	26.9	0.58	156	30.0	27.8	**
42,300	35,000	123,000	38.5	61.0	30.0	0.62	137	27.5	17.0	** Ø
42,100	36,300	127,500	30.6	54.3	29.2	0.57	167			**
42,200	32,400	159,300	29.3	55.0	28.3	0.51	154	38.0	23.8	**
44,200	46,900	132,000	32.5	59.0	31.5	0.60	156	36.3	27.5	* Ø
45,600	47,700	133,000	31.0	58.0	32.0	0.62	152	38.8	27.5	** Ø
44,800	48,800	160,000	22.3	47.0	28.5	0.50	242	29.8	15.0	**
44,300	46,100	148,900	26.8	48.5	30.5	0.67	186	26.0	16.0	** Ø
40,800	49,400	134,800	30.0	58.5	32.0	0.50	169	26.3	20.8	** Ø
43,000	51,500	140,000	23.3	47.5	32.0	0.57	185	22.0	15.0	** Ø
42,500	55,500	149,200	15.5	18.3	28.8	0.49	246	8.5	5.5	**
42,500	36,700	129,000	26.7	49.2	29.7	0.58	201			**
43,700	23,200	150,000	17.3	27.0	28.1	0.48	251	7.8	3.8	**
42,300	28,200	164,000	17.5	27.5	28.0	0.51	268	8.5	5.5	**
42,200	29,200	172,700	20.5	35.0	27.5	0.52	258	10.0	3.5	**

MOLYBDENUM-FREE STEELS. DATA  
NOT USED IN CONSTRUCTING CURVES.

0.5% Mo

0.1% C

1.0% Mo

MOLYBDENUM-FREE STEELS. DATA NOT  
USED IN CONSTRUCTING CURVES.

0.5% Mo

0.2% C

1.0% Mo





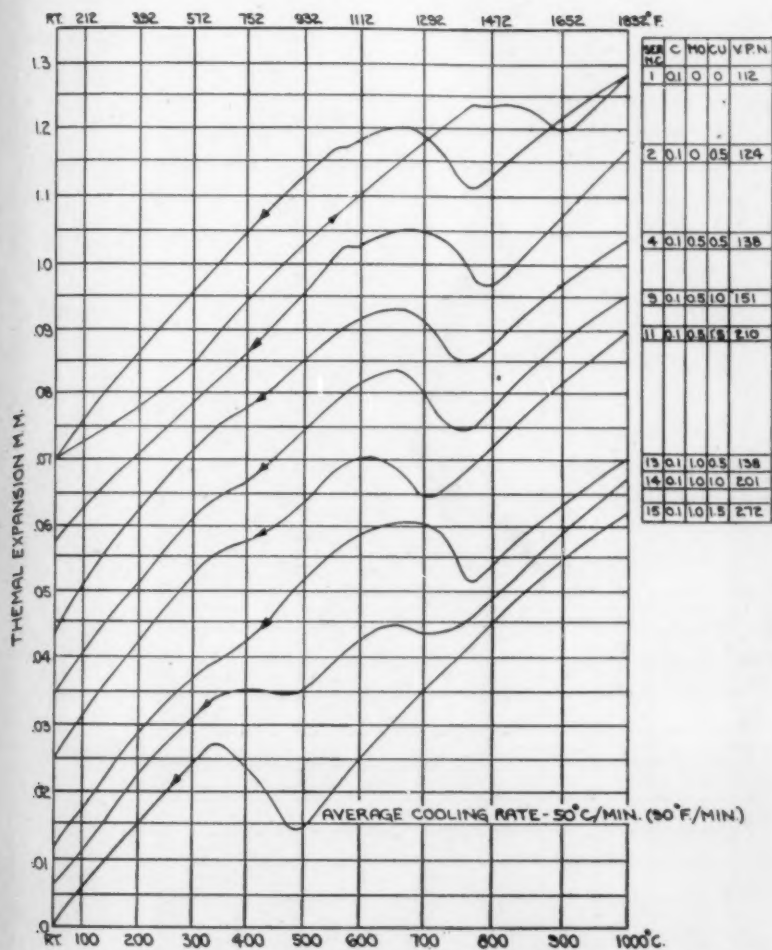


FIG. 2.—THERMAL COOLING CURVES OF CARBON-MOLYBDENUM STEELS CONTAINING 0.1 PER CENT OF CARBON AND VARYING AMOUNTS OF COPPER.

been omitted in the rest of the curves (Figs. 2 and 3) and only the cooling branches reproduced. All resultant dilatometer specimens were tested for Vickers\* hardness and microexamined.

16. In steels containing 0.1 per cent carbon and no molybdenum (nos. 1 and 2, Fig. 2), the transformation on cooling starts at about 780° C. (1440° F.) and comes to completion at about 560° C. (1040° F.). The 0.5 per cent copper present in steel no. 2 did not produce any appreciable effect. In steel no. 4, containing the same carbon, 0.5 per cent molybdenum and 0.5 per cent copper, the transformation is slightly suppressed. Moreover, a small part of the transformation is not completed until the temperature

\*Vickers hardness for these steels is directly comparable to Brinell.

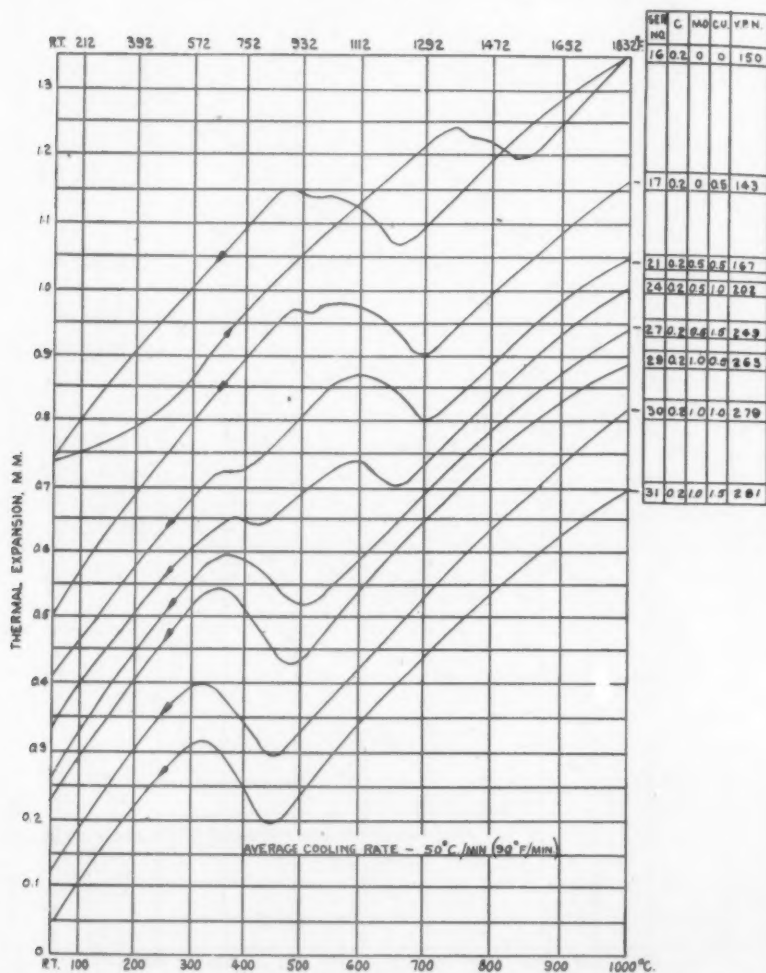


FIG. 3—THERMAL COOLING CURVES OF CARBON-MOLYBDENUM STEELS CONTAINING 0.2 PER CENT OF CARBON AND VARYING AMOUNTS OF COPPER.

of about 380° C. (720° F.) is reached. With progressively increasing contents of copper (nos. 9 and 11), the beginning of the transformation occurs at correspondingly slightly lower temperatures, and the suppressed portion of it (at about 380° C, or 720° F.) becomes a little more pronounced. The latter phenomenon is associated with an increase in hardness produced by the same cooling rate, from about VPN.\* 112 to 210 (Fig. 2).

17. The increase in hardness is also indicated by the appearance of the sorbitic (Widmanstätten) pattern in the resultant structure. Figure 4 presents

\*Vickers Penetration Number.

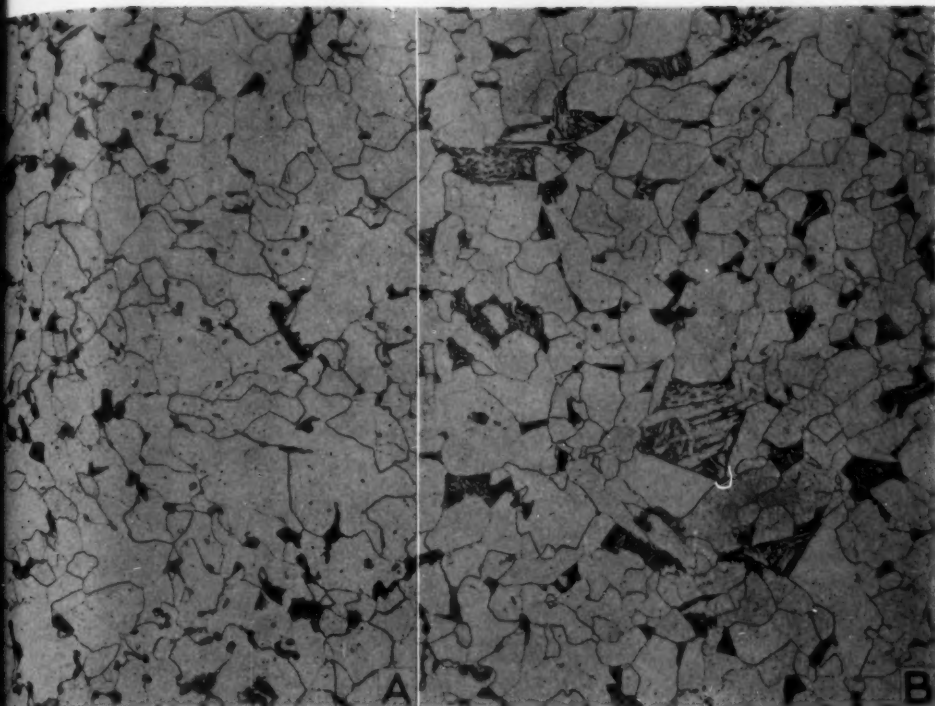
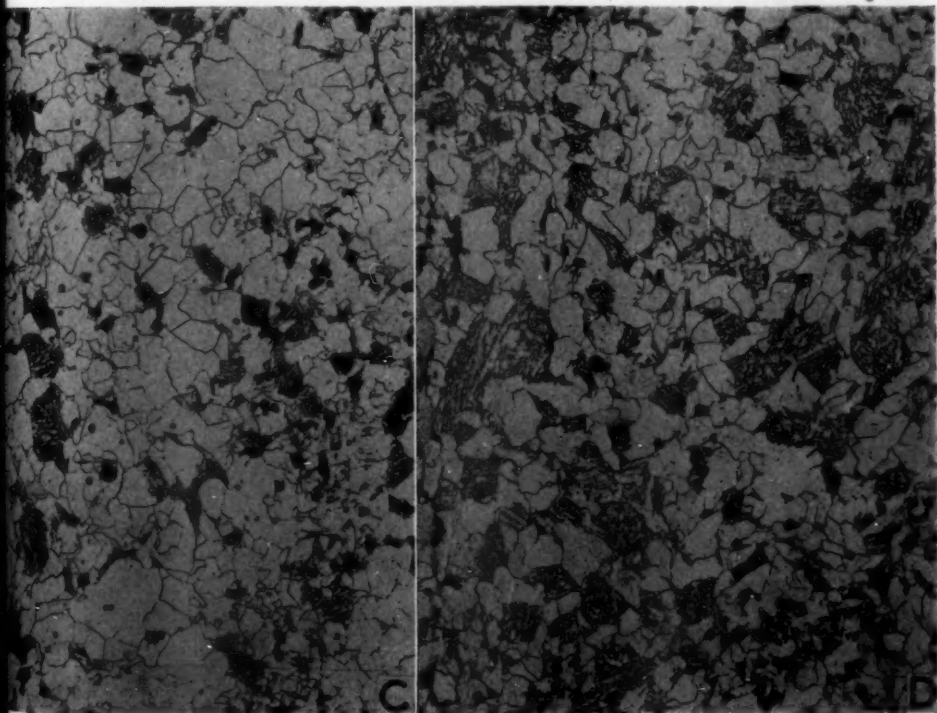


FIG. 4—MICROSTRUCTURES OF STEELS CONTAINING VARIOUS AMOUNTS OF CARBON-MOLYBDENUM AND COPPER. ETCHED IN NITAL. MAGNIFICATION  $\times 150$ . A—SERIAL NO. 2, (FIG. 2) CARBON, 0.1 PER CENT, MOLYBDENUM, ZERO, COPPER, 0.5 PER CENT. B—SERIAL NO. 4, (FIG. 2) CARBON, 0.1 PER CENT, MOLYBDENUM, 0.5 PER CENT, COPPER, 0.5 PER CENT. C—SERIAL NO. 9, (FIG. 2) CARBON, 0.1 PER CENT, MOLYBDENUM 0.5 PER CENT, COPPER, 1.0 PER CENT. D—SERIAL NO. 11, (FIG. 2) CARBON 0.1 PER CENT, MOLYBDENUM, 0.5 PER CENT, COPPER, 1.5 PER CENT.



structures of four steels of the group now being discussed. Figure 4-A, representing steel no. 2, which does not develop any suppressed transformation with the given cooling rate, is composed of ferrite and sharply defined pearlite.

18. In the structure of steel no. 4 (Fig. 4-B), which, with the same cooling rate, develops a slight suppressed transformation (Fig. 2), we observe, in addition to the above two constituents, a certain amount of "diluted pearlite" with Widmanstätten pattern. With the increase in the degree of suppressed transformation (Figs. 4-C and D, corresponding to curves nos. 9 and 11, Fig. 2), the amount of the Widmanstätten pattern increases.

19. In steels containing 0.1 per cent carbon, 1.0 per cent molybdenum, and progressively increasing amounts of copper (nos. 13, 14 and 15, Fig. 2), the suppressed transformation develops even more rapidly than in the preceding group. The corresponding hardness of the dilatometer specimens increases from VPN. 138 to 272. The cooling curve of steel no. 13 (0.1 per cent carbon, 1.0 per cent molybdenum and 0.5 per cent copper, Fig. 2) has a slight suppressed transformation, and the structure of the resultant dilatometer specimen is similar to that of Fig. 4-B.

20. Structure of no. 14 (0.1 per cent carbon, 1.0 per cent molybdenum and 1.0 per cent copper) is represented in Fig. 5. Because of a rather pronounced suppressed transformation (Fig. 2), normal pearlite is completely absent and instead of it we have the "diluted pearlite" with Widmanstätten pattern, in the matrix of ferrite. In steel no. 15 (0.1 per cent carbon, 1.0 per cent molybdenum and 1.5 per cent copper, Fig. 2), the entire transformation is suppressed, the hardness is rather high (VPN. 272) and the resultant

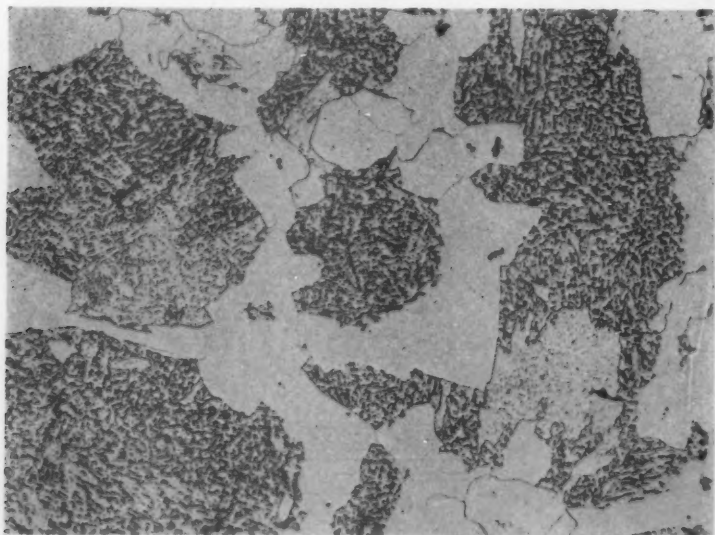


FIG. 5—MICROSTRUCTURE OF STEEL CONTAINING 0.1 PER CENT CARBON, 1.0 PER CENT MOLYBDENUM, 1.0 PER CENT COPPER. SERIAL NO. 14 (FIG. 2). ETCHED IN NITAL. MAGNIFICATION  $\times 150$ .

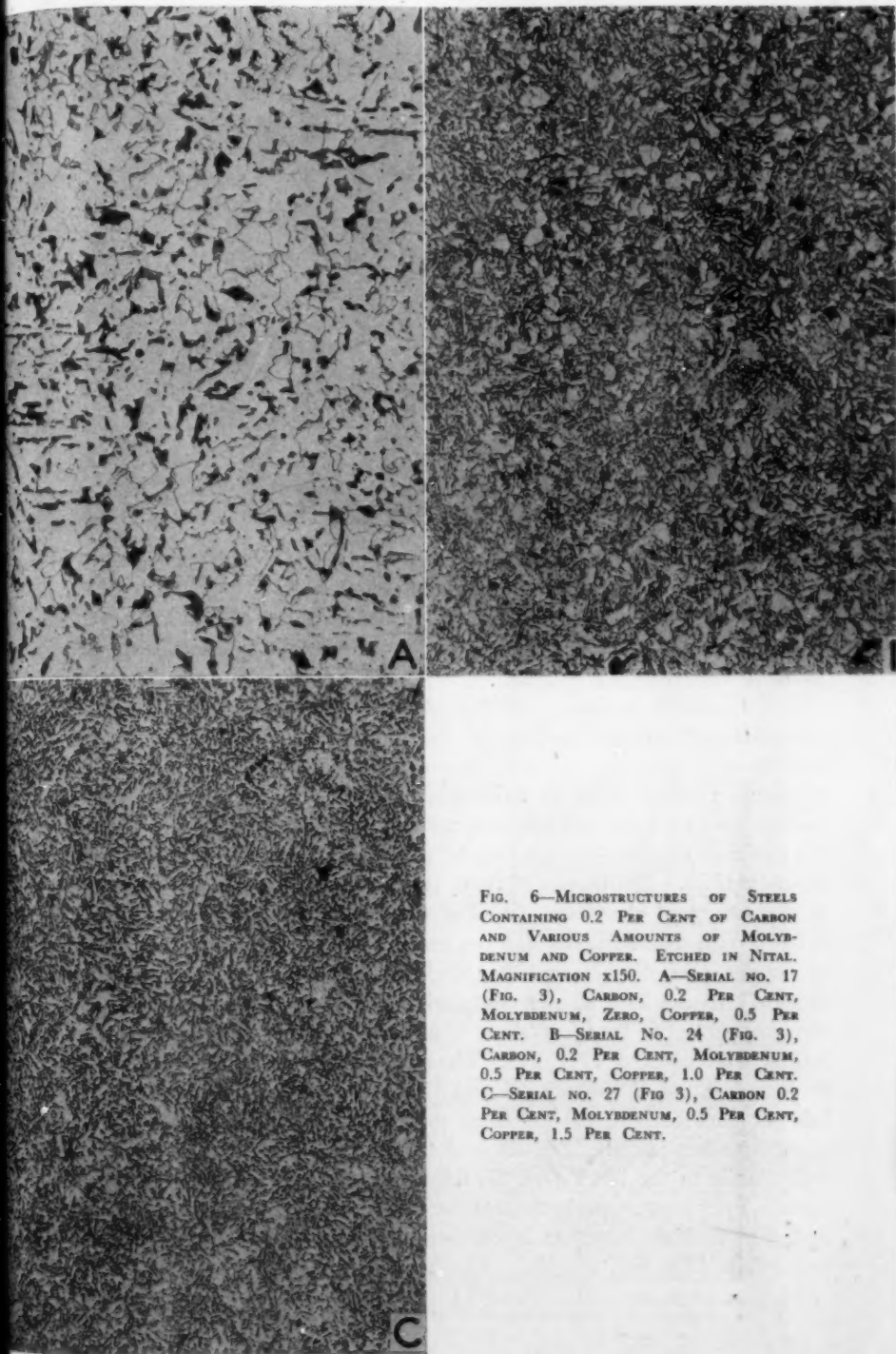


FIG. 6—MICROSTRUCTURES OF STEELS CONTAINING 0.2 PER CENT OF CARBON AND VARIOUS AMOUNTS OF MOLYBDENUM AND COPPER. ETCHED IN NITAL. MAGNIFICATION  $\times 150$ . A—SERIAL NO. 17 (FIG. 3), CARBON, 0.2 PER CENT, MOLYBDENUM, ZERO, COPPER, 0.5 PER CENT. B—SERIAL NO. 24 (FIG. 3), CARBON, 0.2 PER CENT, MOLYBDENUM, 0.5 PER CENT, COPPER, 1.0 PER CENT. C—SERIAL NO. 27 (FIG. 3), CARBON 0.2 PER CENT, MOLYBDENUM, 0.5 PER CENT, COPPER, 1.5 PER CENT.



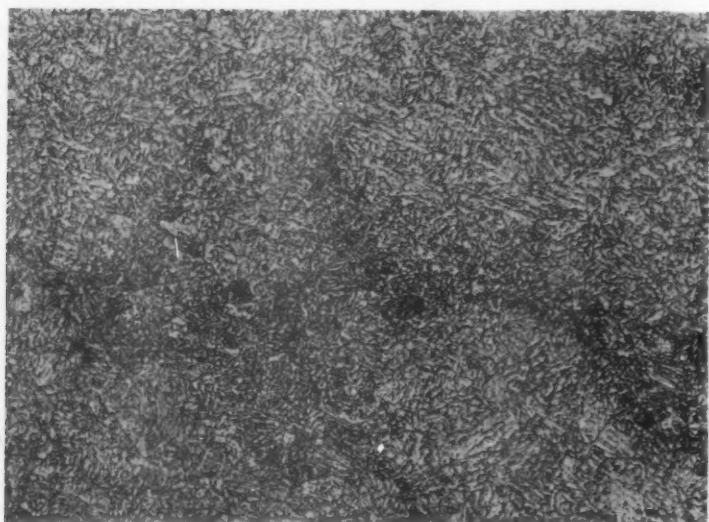


FIG. 7—MICROSTRUCTURE OF STEEL CONTAINING 0.2 PER CENT CARBON, 1.0 PER CENT MOLYBDENUM, 1.0 PER CENT COPPER. SERIAL NO. 30 (FIG. 3). ETCHED IN NITAL. MAGNIFICATION  $\times 150$ .

structure is similar to Figs. 6-C or 7, i.e., is composed of an intimate mixture of carbides and ferrite. (Structure of Fig. 7 resembles one frequently referred to as "lower bainite").

21. Figure 3 presents a similar sequence of dilatometer curves for steels containing 0.2 per cent carbon. In steel no. 16 (0.2 per cent carbon, zero per cent molybdenum, zero per cent copper), transformations on cooling, because of higher carbon, occur at temperatures lower than in no. 1 (0.1 per cent carbon, zero per cent molybdenum, zero per cent copper, Fig. 2). Addition of 0.5 per cent copper (no. 17, Fig. 3) practically does not change the thermal characteristics. Hardnesses of these two steels (VPN. 150 and 143), as well as the structural characteristics (Fig. 6-A), are also almost identical.

22. With the addition of 0.5 per cent molybdenum and progressive increase in copper (nos. 21, 24 and 27, Fig. 3), the thermal sluggishness develops rapidly. In no. 27 (0.2 per cent carbon, 0.5 per cent molybdenum, 1.5 per cent copper), the transformation is completely suppressed and the resultant hardness increases to VPN. 249. The structural characteristics are represented by Figs. 6-B and C (for nos. 24 and 27, respectively). In the former (no. 24, 0.2 per cent carbon, 0.5 per cent molybdenum, 1.0 per cent copper), the transformation is split (Fig. 3) and some free ferrite can be observed (Fig. 6-B), while in the latter (no. 27, 0.2 per cent carbon, 0.5 per cent molybdenum, 1.5 per cent copper), the transformation is completely suppressed (Fig. 3) and the resultant structure is composed of an intimate mixture of carbides and ferrite (Fig. 6-C).

23. In steels nos. 29, 30 and 31, containing 0.2 per cent carbon, 1.0 per



cent molybdenum, and progressively increasing amounts of copper (Fig. 3), transformations are completely suppressed, in all three cases the resultant hardnesses vary from VPN. 263 to 281, structures are all identical and are represented by Fig. 7.

24. The conclusion that can be derived from these studies is that progressively larger amounts of copper (up to 1.5 per cent Cu) increase the thermal sluggishness of carbon-molybdenum steels containing 0.1 and 0.2 per cent carbon, increase their air hardenability and promote formation of "diluted pearlite" in the resultant structures.

25. It should be noted that increasing amounts of carbon and molybdenum have a more pronounced effect in suppressing transformations than copper, and that manganese also acts in the same general direction, but its effect in amounts under one per cent is quite small. However, within each of four groups of steels just discussed (nos. 4, 9 and 11, nos. 13, 14 and 15, nos. 21, 24 and 27, and nos. 29, 30 and 31, Figs. 1 and 2) the progressive increase in thermal sluggishness can be attributed to copper only, except for the slight effect of manganese.

26. For comparison's sake, Fig. 8 presents a similar dilatometer curve for a conventional carbon-molybdenum steel, containing 0.28 per cent carbon (complete analysis is given in Fig. 8). It may be noted that with the same cooling rate, its transformation is completely suppressed to temperatures

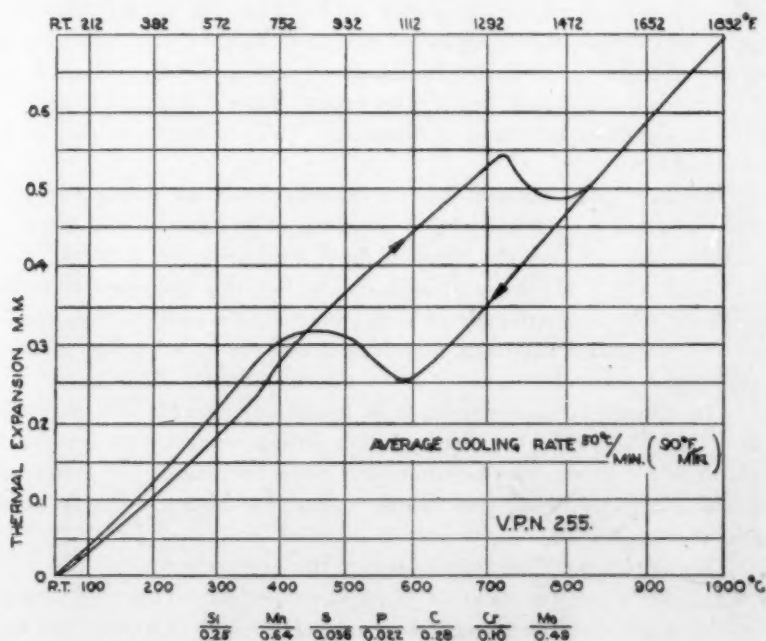


FIG. 8—THERMAL CURVE OF A CONVENTIONAL CARBON-MOLYBDENUM STEEL.

below 600° C. (1112° F.), that its resultant hardness is V.P.N. 255 and structure similar to Fig. 7.

27. It may be mentioned in passing that the relationship between the shape of thermal curves, resultant hardness and structures, is by no means restricted to this particular group, and has been observed in a wide variety of steels<sup>78</sup>.

#### PHYSICAL PROPERTIES

28. Figures 9 and 10 are graphic representations of data given in Table 3, on the effect of copper on physical properties of carbon-molybdenum steels containing 0.1 per cent carbon, and 0.5 and 1.0 per cent molybdenum, respectively. Figures 11 and 12 are similar graphs for steels containing 0.2 per cent carbon. In each figure, physical properties of the same steels have been plotted after all of them were normalized from 1750 to 1800° F. (950 to 980° C.) and then in separate groups drawn at (1) 1000° F. (540° C.), (2) 1150° F. (620° C.) and (3) 1300° F. (700° C.). In all cases, there was a certain scattering of the points, due to the inevitable experimental error, so that the curves represent average values, somewhat on the conservative side. This is particularly true about Figs. 9 and 11, where a larger number of test data were plotted.

29. In each figure, the specification requirements for the cast carbon-molybdenum steel are drawn as dotted lines. The conclusions that may be reached from studying these graphs are that copper very considerably increases the tensile strength, yield point, breaking strength and yield ratio. Proportional limit is also increased in all cases except those of Figs. 10-C and 12-C, where it has a slight tendency to decrease. This, probably, is due to some experimental error.

30. The increase in strength in some instances is almost twofold (Figs. 9-A and 10-C), and is considerably more pronounced in steels containing 0.1 per cent carbon (Figs. 9 and 10) than in those containing 0.2 per cent carbon (Fig. 11 and 12). Hardness also increases, but this increase is relatively small. Elongation and reduction of area tend to be lowered, but this tendency is not very great, and decreases to values below the specification minimums only occur in a few cases.

31. The Charpy impact resistance at room temperature, and particularly that at -25° F. (-31° C.), has a rather strong tendency to decrease, but even so, there are many cases where impact resistance values, satisfactory from the specification standpoint and at the same time associated with superior strength, can be found.

32. The drawing temperature (within the specified limits) has a relatively small effect on the resultant physical properties. The most beneficial one, in the sense of high strength associated with high ductility, appears to be about 1150° F. (620° C.). No pronounced precipitation hardening effect was disclosed by these experiments, in all probability because this phenomenon

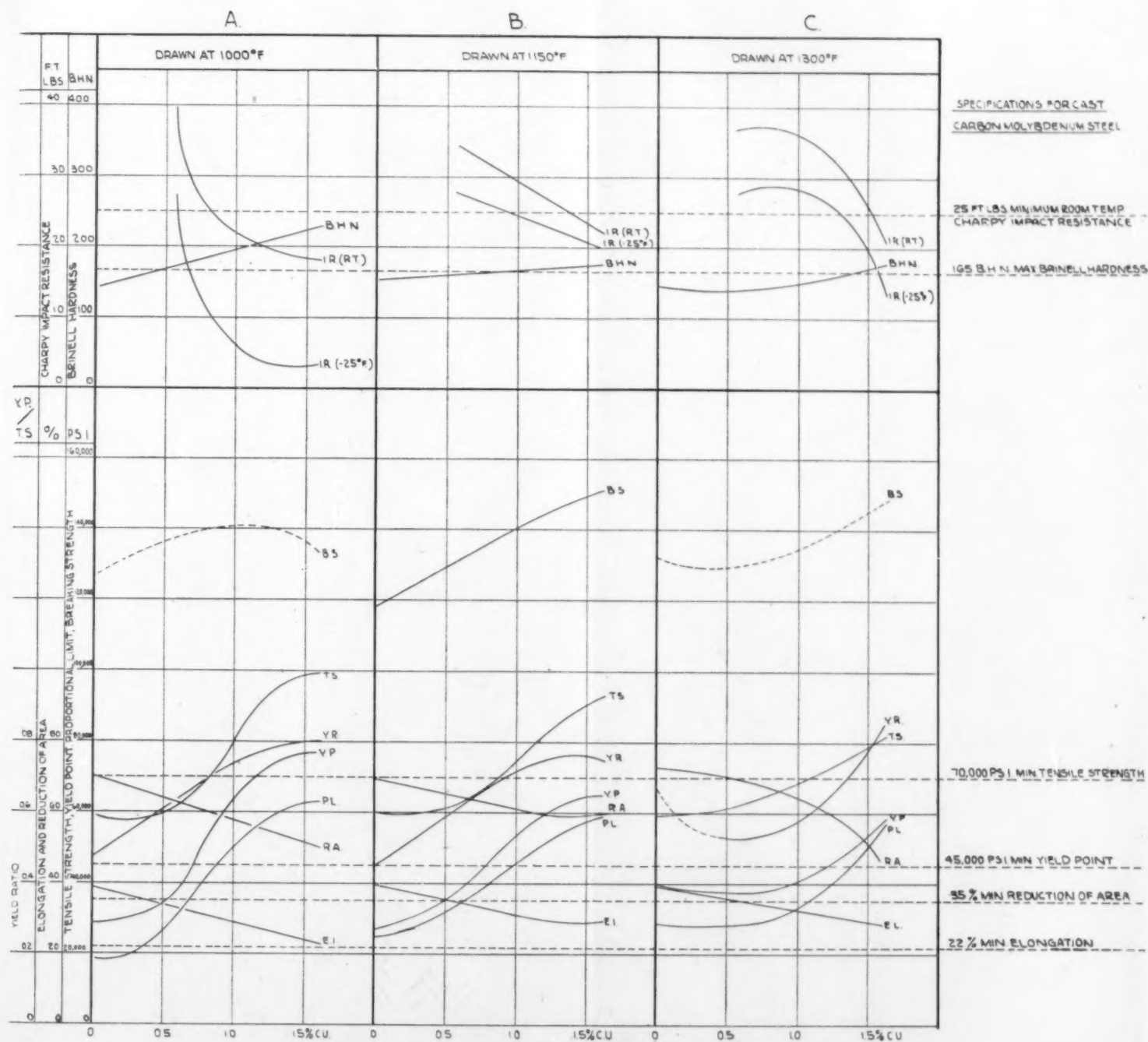
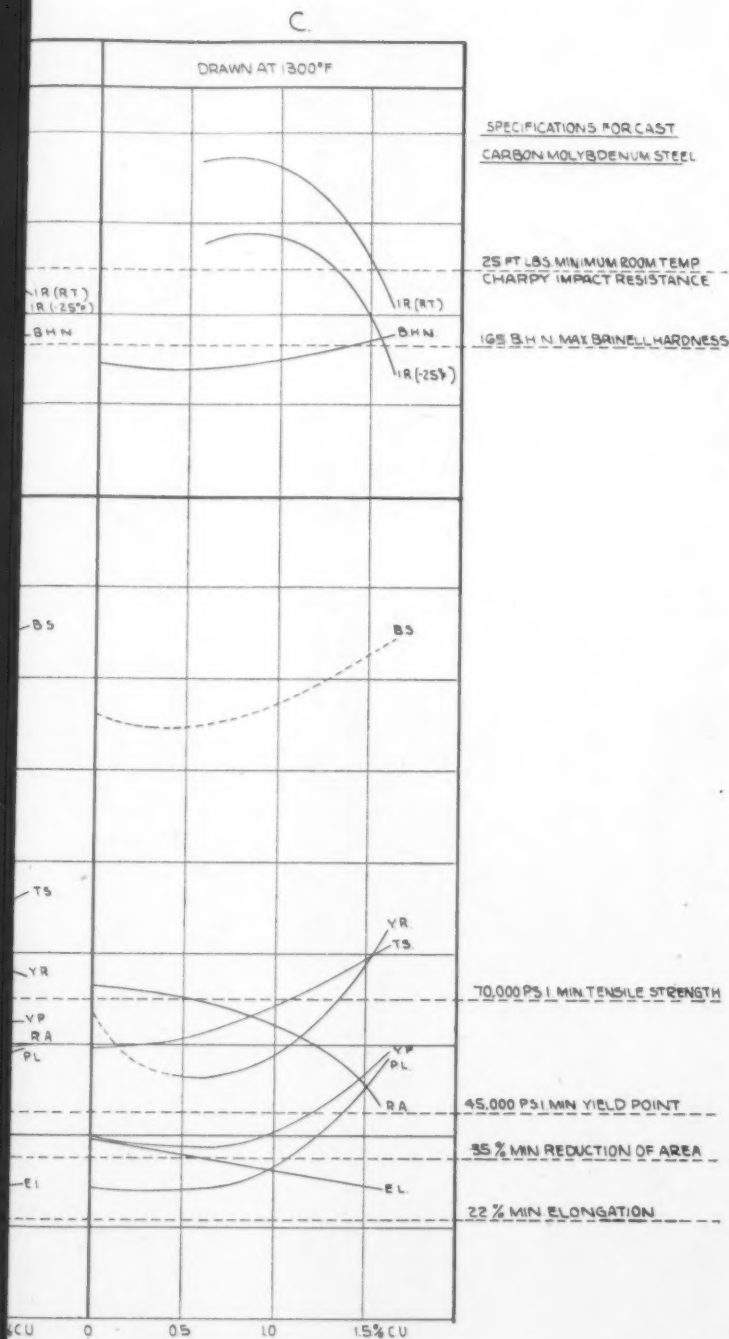


FIG. 9—EFFECT OF COPPER ON PHYSICAL PROPERTIES OF CAST STEELS CONTAINING 0.1 PER CENT CARBON AND 0.5 PER CENT MOLYBDENUM. NORMALIZED AT 1750 TO 1800° F.



CAST STEELS CONTAINING 0.1 PER CENT CARBON  
NORMALIZED AT 1750 TO 1800° F.

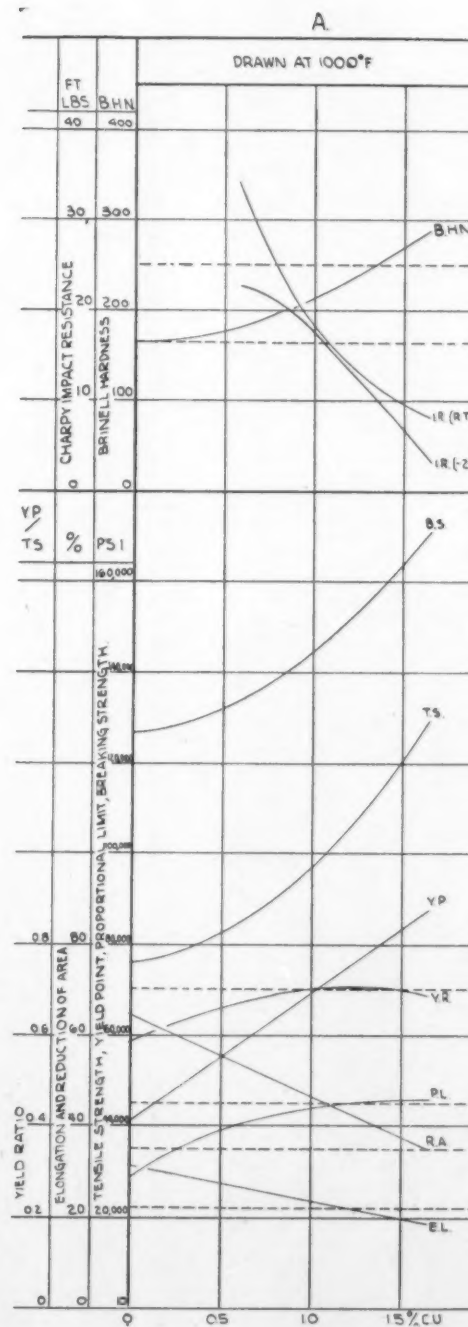
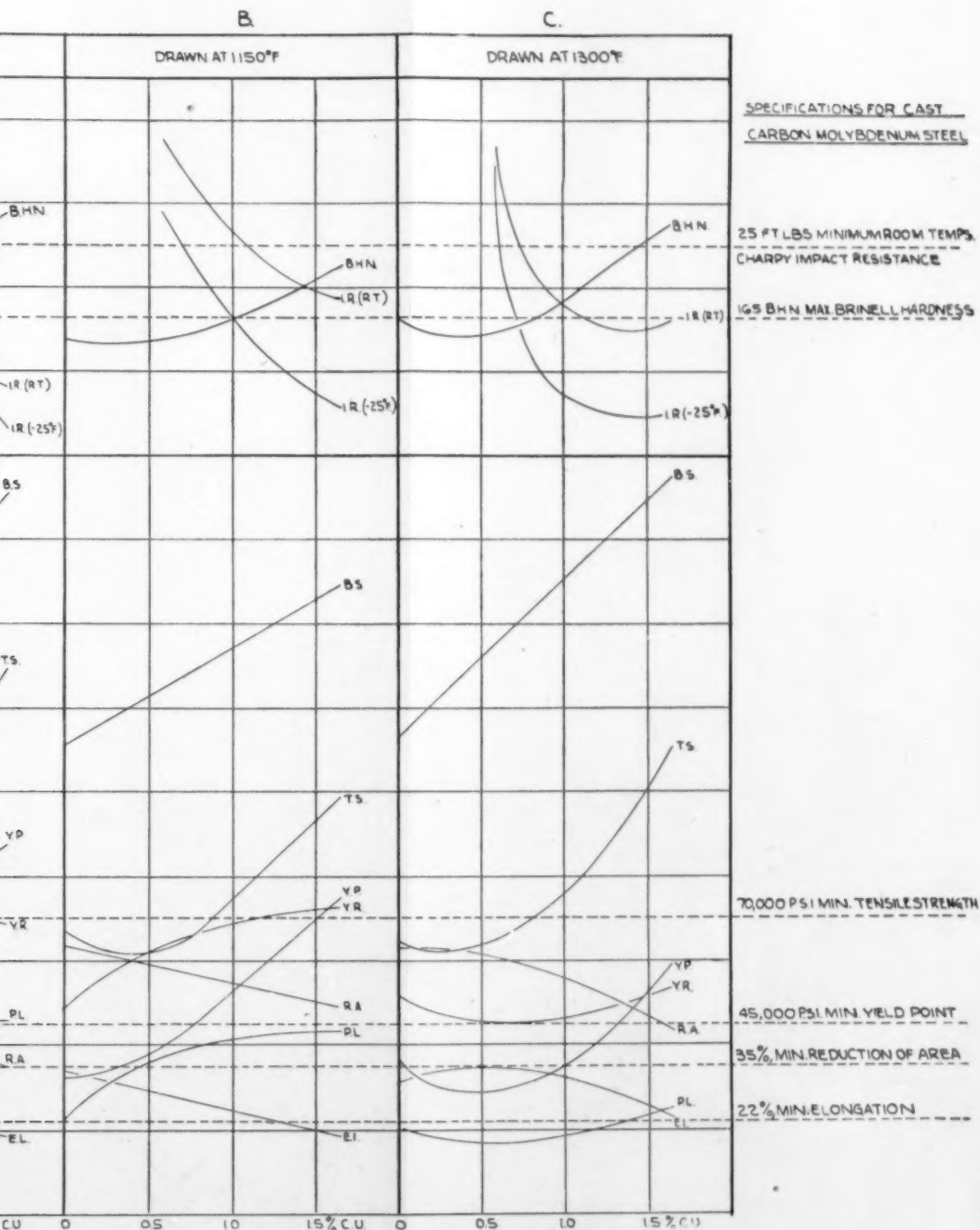


FIG. 10—EFFECT OF



EFFECT OF COPPER ON PHYSICAL PROPERTIES OF CAST STEELS CONTAINING 0.1 PER CENT CARBON  
AND 1.0 PER CENT MOLYBDENUM. NORMALIZED AT 1750 TO 1800° F.

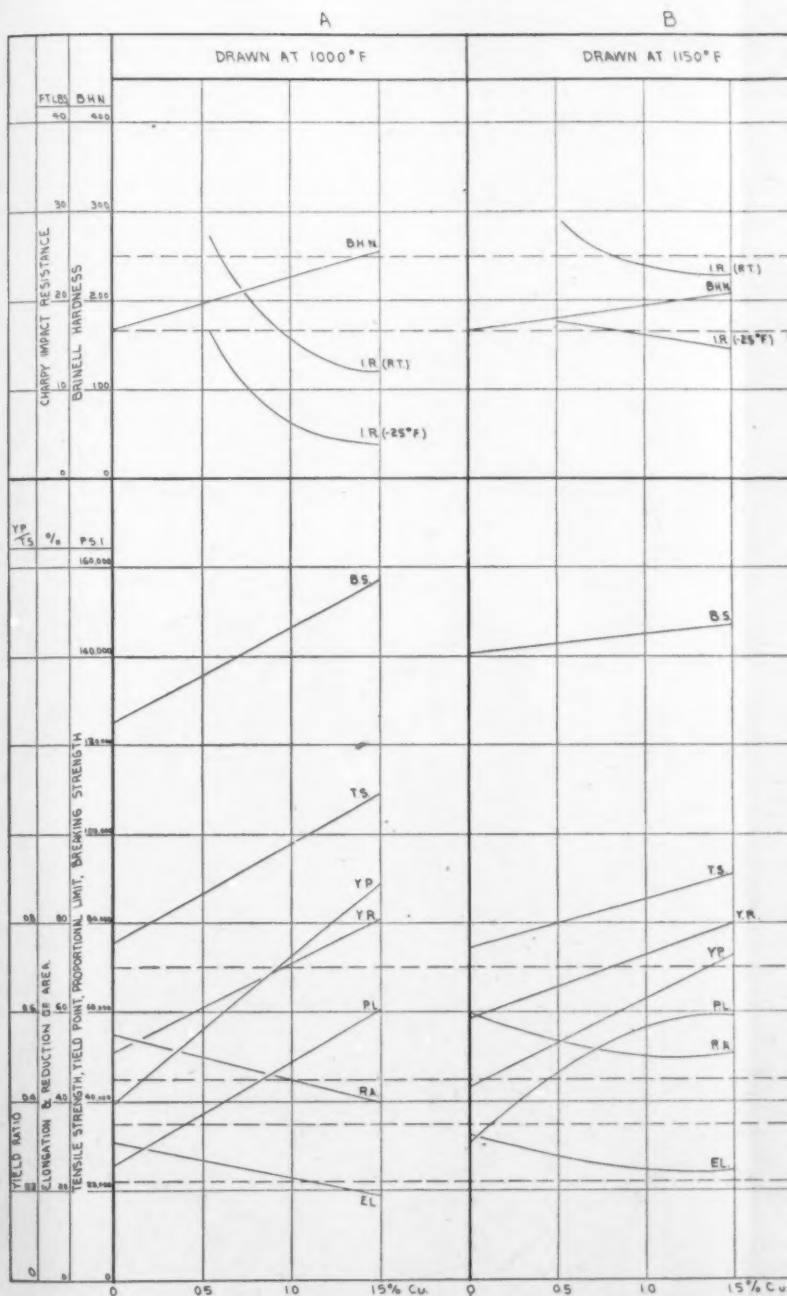
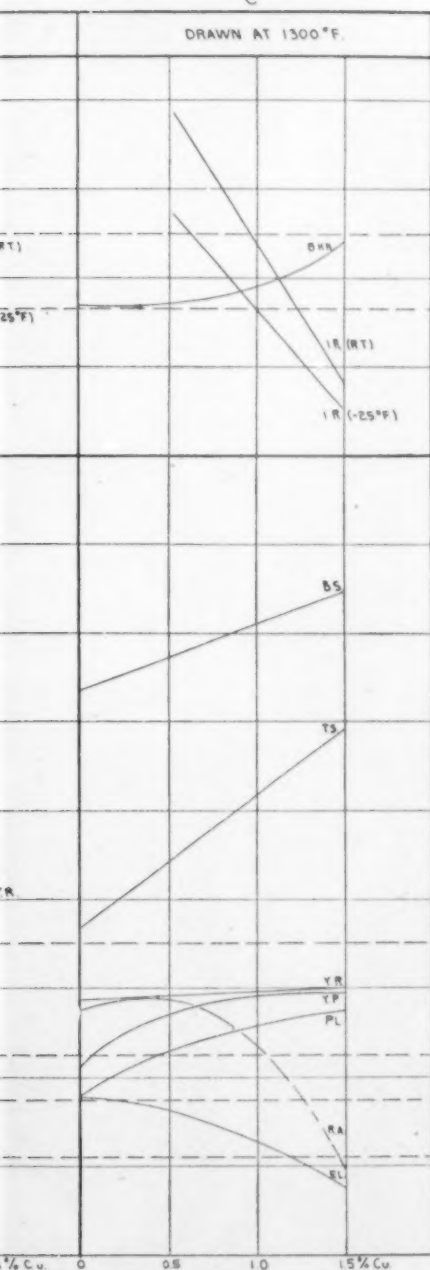


FIG. 11—EFFECT OF COPPER ON PHYSICAL PROPERTIES OF CUPRO-MOLYBDENUM AND 0.5 PER CENT MOLYBDENUM. NORMAL



DRAWN AT 1300°F



SPECIFICATION FOR CAST  
CARBON MOLYBDENUM STEEL

25 FT LBS MINIMUM ROOM TEMPERATURE  
CHARPY IMPACT RESISTANCE

165 BHN MAXIMUM BRINELL HARDNESS

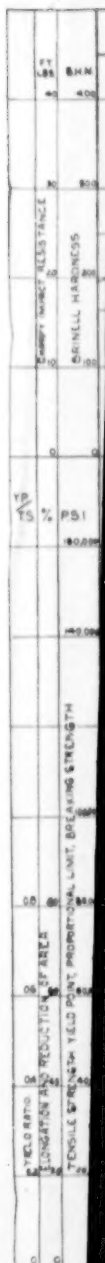
70000 PSI MINIMUM TENSILE STRENGTH

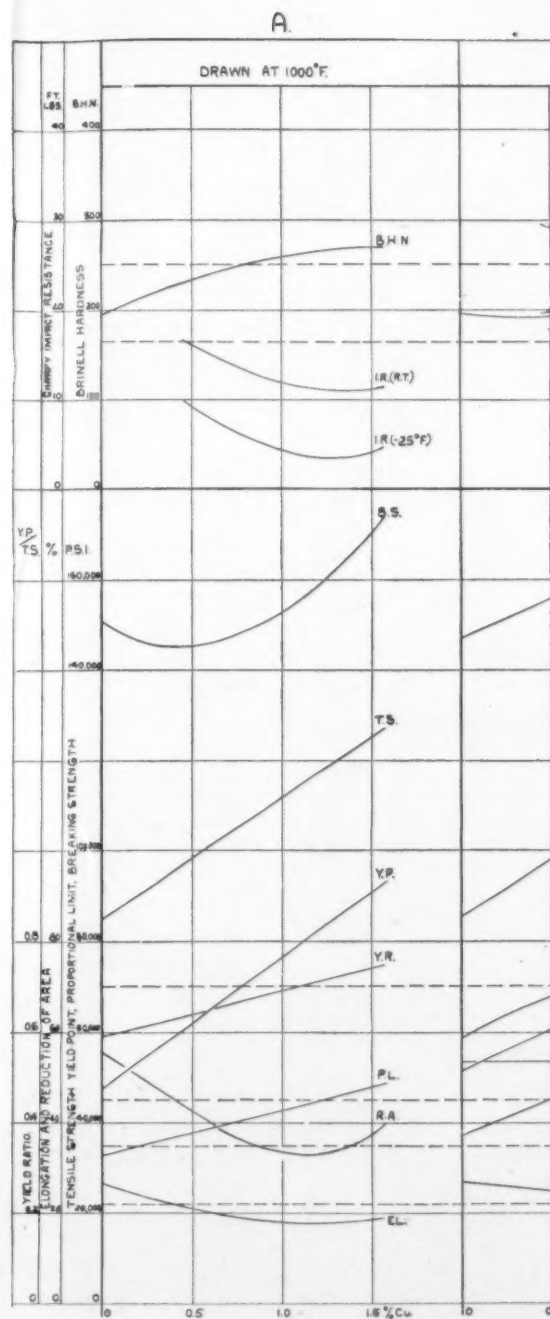
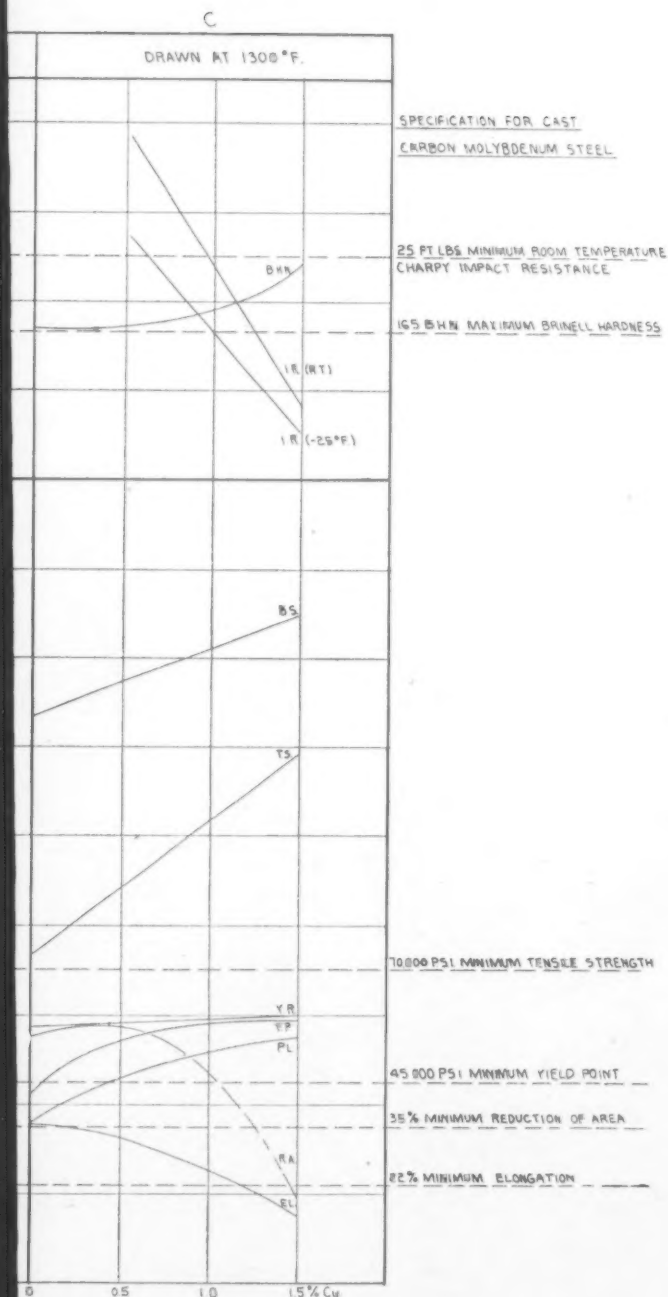
45 000 PSI MINIMUM YIELD POINT

35% MINIMUM REDUCTION OF AREA

22% MINIMUM ELONGATION

OF CAST STEELS CONTAINING 0.2 PER CENT CARBON  
NORMALIZED AT 1750 TO 1800° F.





STEELS CONTAINING 0.2 PER CENT CARBON  
DRAWN AT 1750 TO 1800° F.

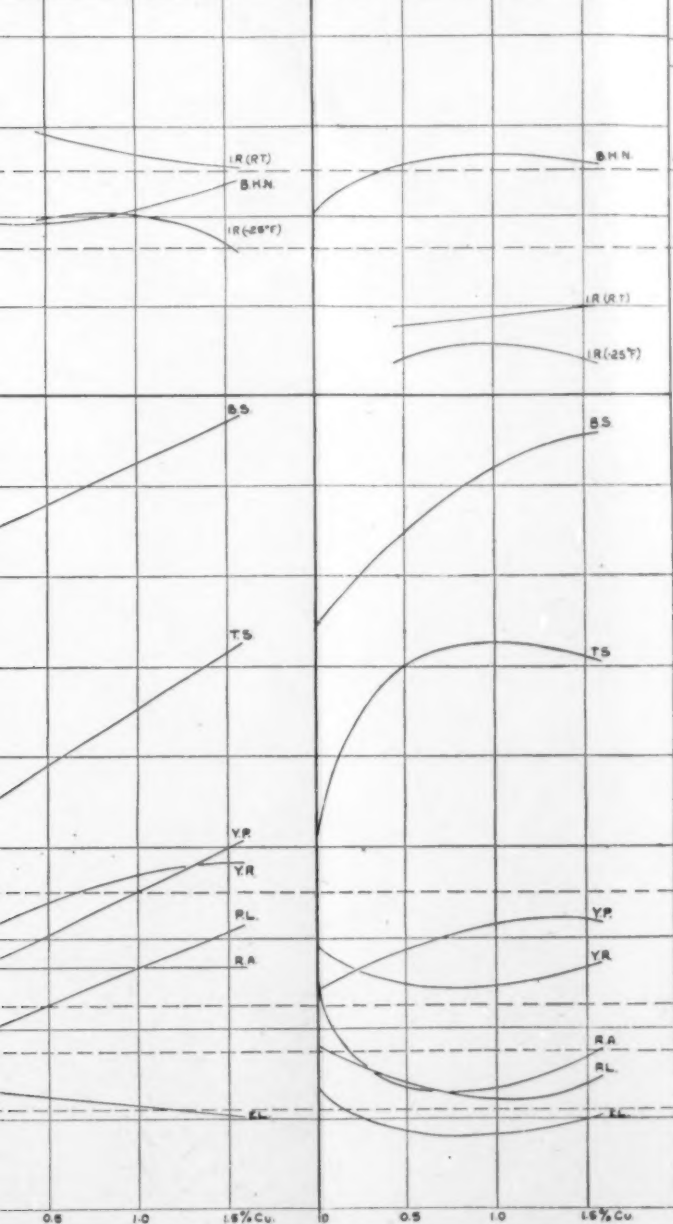
FIG. 12—EFFECT OF COPPER ON  
AND 1.0 PER CENT

B

C.

DRAWN AT 1150°F

DRAWN AT 1300°F



SPECIFICATIONS FOR CAST

CARBON-MOLYBDENUM STEEL

25 FT LBS MINIMUM ROOM TEMPERATURE

CHARPY IMPACT RESISTANCE

165 BHN MAXIMUM BRINELL HARDNESS

70,000 PSI MINIMUM TENSILE STRENGTH

45,000 PSI MINIMUM YIELD POINT

38% MINIMUM REDUCTION OF AREA

22% MINIMUM ELONGATION

OVER ON PHYSICAL PROPERTIES OF CAST STEELS CONTAINING 0.2 PER CENT CARBON  
1.0 PER CENT MOLYBDENUM. NORMALIZED AT 1750 TO 1800° F.



manifests itself at lower temperatures. Lower drawing temperatures, on the other hand, would be prohibitive because of insufficiently high resultant ductility.

33. Increased molybdenum also contributes somewhat to strengthening of the steels (compare Figs. 9 vs. 10 and 11 vs. 12). This effect, however, is small as compared to that of copper. Moreover, indications are that higher molybdenum may have a detrimental effect in unduly reducing the ductility. Increased manganese also increases the strength, but its effect has not yet been studied well enough to draw any definite conclusions.

34. In general, this study presents a rather wide selection of steels with properties which can satisfy various requirements. For example, a steel containing 0.5 per cent molybdenum, 1.0 per cent copper and only 0.1 per cent carbon, drawn at 1150° F. (620° C.) (Fig. 9-B), will pass all the specification requirements of a standard carbon-molybdenum steel, which normally (without copper) must have over 0.2 per cent carbon.

35. The same is true about a similar steel, similarly treated, containing 1.0 per cent molybdenum (Fig. 10-B). Passing over to steels containing 0.2 per cent carbon, several compositions can be found which would satisfy requirements belonging to higher specifications brackets, like those of chromium-molybdenum steels (Fig. 12-B)\*.

36. It thus appears that the most promising steels, in the light of the present investigation, are those containing 0.1 and 0.2 per cent carbon, 0.5 and 1.0 per cent copper and about 0.5 per cent molybdenum. These compositions thus have been reproduced several times (Table 3) and tested. Testing shows that the resultant properties readily can be duplicated.

37. Preliminary creep experiments on steels nos. 9 and 30 (0.1 per cent C, 0.5 per cent Mo, 1.0 per cent Cu and 0.2 per cent C, 1.0 per cent Mo and 1.0 per cent Cu, respectively) performed at 850° F. (450° C.) indicate that their creep resistance falls on the low side within the limits usually obtained with carbon-molybdenum steels. Moreover, no. 30 is showing better results than no. 9. Tentative conclusions that may be drawn are that copper has a tendency to reduce the creep resistance, but that this effect may be corrected by raising molybdenum. Further creep research is still in progress.

#### WELDING EXPERIMENTS

38. All experimental castings, tees, were heat treated by normalizing at 1750 to 1800° F. (950 to 980° C.) and drawing at 1150° F. (680° C.). Then they were cut longitudinally, deep etched and examined for hot tears. They were found to be quite sound and surprisingly free of various defects frequently observed in steel castings. After that, a welding test piece was cut out from each half of the casting, as shown in Fig. 1.

39. The original contact surfaces of the two halves from each casting

\*No claims are being made regarding the corrosion resistance similar to that of the chromium-molybdenum steels.

were machined off, forming a "V" groove, and then were arc welded together to form the original shape, using standard carbon-molybdenum electrodes of the following nominal composition: Silicon, 0.12 per cent, manganese, 0.35 per cent, carbon, 0.10 per cent, and molybdenum 0.50 per cent. No subsequent stress-relieving treatment has been applied.

40. From the middle part of each resultant "trough," a cross-sectional U-shaped test piece of about  $\frac{1}{2}$ -in. thickness was cut out and roughly polished. A hardness survey was made over every one of these test pieces, using a Vickers Hardness tester and taking readings at about  $\frac{1}{8}$ -in. intervals across the weld and the affected zone.

41. For the sake of comparison, a similar experiment was performed on a casting made from a conventional carbon-molybdenum steel, represented by the thermal curve and the analysis in Fig. 8. Figure 13 is a photograph of the latter test piece (slightly etched) indicating hardness impressions and readings.

#### *Hardness Distribution*

42. Figure 14 is a graphic representation of hardness distribution across the welds and the affected zones, in steels containing 0.1 per cent carbon: (A—steels containing 0.5 per cent molybdenum and 0.5 per cent copper, and B—steels containing 0.5 per cent molybdenum and 1.0 per cent copper). Figures 15-A and 15-B are similar graphs for steels containing 0.2 per cent carbon. In each case, hardness distribution in the conventional carbon-molybdenum steel is included for comparison's sake.

43. It is interesting to note that in most cases the weld itself is relatively soft, and that the hardest portions are in the affected zone, right adjacent to the weld (Figs. 14-B, 15-A and 15-B). This is not true about low carbon, low copper steels (Fig. 14-A), where no excessive hardness in the affected zone could be observed. At any rate, the conventional carbon-molybdenum

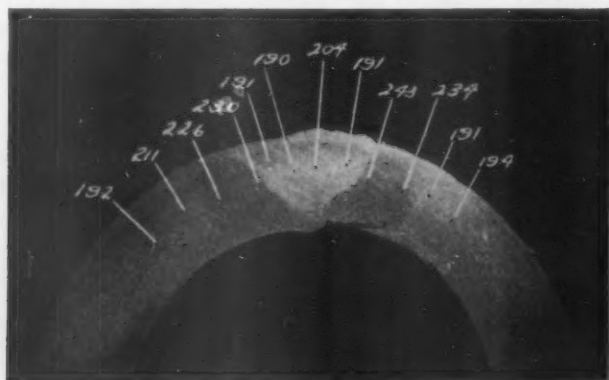


FIG. 13—HARDNESS DISTRIBUTION OVER THE WELD AND THE AFFECTED ZONE IN A CONVENTIONAL CARBON-MOLYBDENUM CAST STEEL.



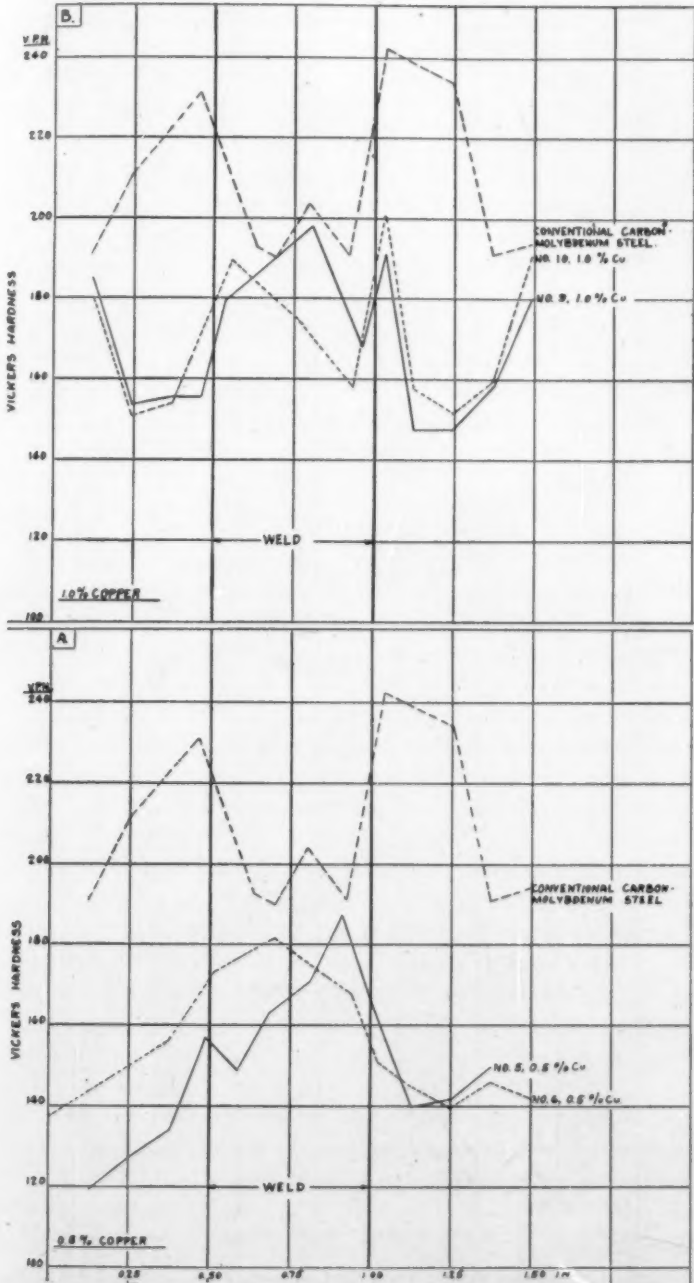


FIG. 14—HARDNESS DISTRIBUTION ACROSS WELDS IN COPPER-MOLYBDENUM STEELS CONTAINING 0.1 PER CENT CARBON AND 0.5 PER CENT MOLYBDENUM.

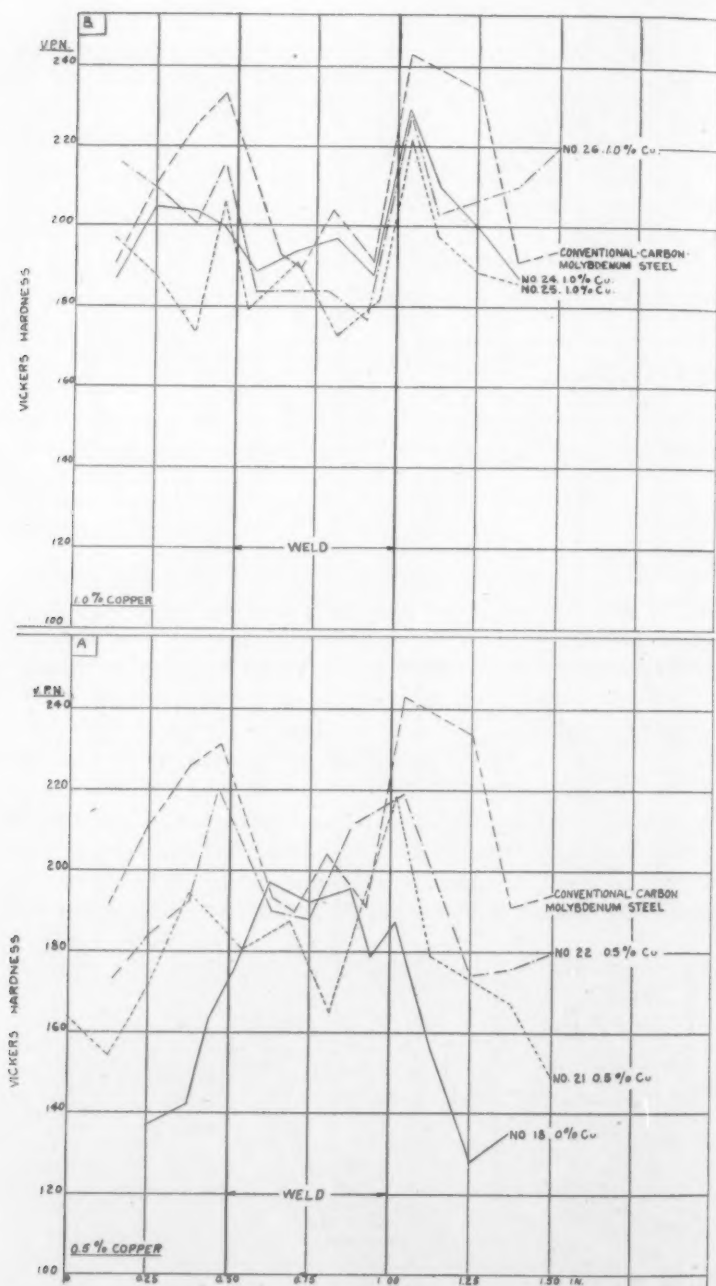


FIG. 15—HARDNESS DISTRIBUTION ACROSS WELDS IN COPPER-MOLYBDENUM STEELS CONTAINING 0.2 PER CENT CARBON AND 0.5 PER CENT MOLYBDENUM.

steel containing higher carbon displayed the greatest hardness, as compared to any composition of this series. Increasing copper appeared to contribute somewhat to the hardening effect (compare Fig. 14-A vs. 14-B, and Fig. 15-A vs. 15-B). However, this hardness increase is relatively small.

44. On the other hand, steels nos. 9 and 10 (Fig. 14-B), if properly heat treated, develop physical properties required from the conventional carbon-molybdenum steel (see Table 3 and Fig. 9-B). One could readily appreciate that from the welding standpoint they are more desirable than the latter.

45. Passing over to Fig. 15, representing hardness distribution in steels containing 0.2 per cent carbon, it may be noted that they develop maximum hardness in the affected zone, adjacent to the weld (serial no. 18, Fig. 15-A, containing only 0.13 per cent carbon, is an exception and acts more like steels in Fig. 14-A). Nevertheless, none of them become as hard as the conventional carbon-molybdenum steel with 0.28 per cent carbon. At the same time, some of them develop properties specified for chromium-molybdenum steels (Table 1, Fig. 11-C), which have very strong thermal sluggishness and air hardenability.

#### SUMMARY

46. Investigation of steels containing 0.1 to 0.2 per cent carbon, 0.5 to 1.0 per cent molybdenum and 0.5 to 1.5 per cent copper, presents a rather interesting selection of materials with wide variation in physical and thermal properties. Increase in copper from zero to 1.5 per cent in steels in which all other chemical ingredients are constant, may cause an increase in strength as much as almost twofold. At the same time, increase in hardness, decrease in ductility and decrease in impact resistance are not large enough to be objectionable.

47. Addition of one per cent copper to a steel, containing 0.1 per cent (max.) carbon and 0.5 per cent molybdenum, develops in the resultant product (after a suitable heat treatment) properties required from a cast carbon-molybdenum steel, containing about 0.25 per cent carbon.

48. Dilatometric analysis and microexamination demonstrate that such a steel is considerably less thermally sluggish and air hardenable than regular carbon-molybdenum steel in which a higher carbon content is specified in order to develop the desired physical properties.

49. Welding experiments and hardness distribution studies over the weld and affected zone show that the maximum hardness thus developed in such and similar compositions is considerably lower than in the conventional carbon-molybdenum steel.

50. In a steel containing about one per cent copper and 0.5 per cent molybdenum, an increase in carbon to 0.2 per cent (max.) produces physical properties comparable to those of chromium-molybdenum steels, which are notorious for their thermal sluggishness and air hardenability. Dilatometric

analysis, microexamination and welding experiments, on the other hand, have demonstrated that such a steel is less thermally sluggish and air hardenable than even the conventional cast carbon-molybdenum steel.

#### ACKNOWLEDGMENTS

51. The authors wish to express their thanks to Crane Co. for permission to publish these results, to H. W. Northrup and J. R. Goldsmith for preparation of the steels, heat treatment and testing, to H. Peterson for making the dilatometric analysis, and to R. Mueller for performing the welding tests.

#### Bibliography

1. Gregg, J. L., and Daniloff, B. N., *THE ALLOYS OF IRON AND COPPER*, Alloys of Iron Monographs, McGraw-Hill Book Co., Inc., New York (1934).
2. Cornelius, H., *KUPFER IM TECHNISCHEN EISEN*, Julius Springer, Berlin, (1940).
3. Anonymous, "*Copper Steel, its Corrosion Resistance*," *METALLURGIST*, Aug. 6, 1927, p. 121.
4. Saklatwalla, B. D., and Demmler, A. W., "*Chromium-Copper Steels as Possible Corrosion Resisting Ferrous Alloy*," *TRANSACTIONS, A.S.S.T.*, vol. 15, no. 1, January 1929, p. 36.
5. Anonymous, "*Steel Containing Copper is Highly Resistant to Atmospheric Corrosion*," *ENGINEERING AND MINING JOURNAL*, vol. 127, no. 24, June 15, 1929, p. 964.
6. Marzahn, W., and Pusch, W., "*Corrosion Resistance of Structural Copper Bearing Steels*," *KORROSION UND METALLSCHUTZ*, vol. 7, no. 2, Feb. 1931, p. 34.
7. Anonymous, "*Copper Steels, Their Corrosion Resistance*," *CUivre DE LAITON*, vol. 4, June 1931, p. 275, Nov. 15, 1931, p. 495.
8. Carius, C., "*Corrosion Phenomenon Observed on Copper Bearing Steels with Particular Reference to the Attack by Sea Water*," *KORROSION UND METALLSCHUTZ*, vol. 7, Aug. 1931, p. 181.
9. Anonymous, "*Characteristics of Copper Steels*," *METALLURGIST*, vol. 3, Aug. 28, 1931, p. 117.
10. Cassel, H., and Todt, F., "*Under-Water Corrosion of Copper Bearing Steels*," *METALLWIRTSCHAFT*, vol. 10, Dec. 11, 1931, p. 936.
11. Friend, J. N., and West, W., "*The Resistance of Copper-Nickel Steels to Sea Action*," *JOURNAL, British Iron and Steel Inst.*, vol. 123, no. 1, 1931, p. 501.
12. Copper development Assn., Thames House, Millbank London, "*Copper Steels to Resist Corrosion*," Publ. no. 4, 1935.
13. Stuebing, A. F., "*High Tensile Steels for Light Weight Construction*," *METALS PROGRESS*, July, 1938, p. 37.
14. Bardenheuer, P., and Thanheiser, G., "*Experiments on the Effect of Copper on the Acid Resistance of Low Carbon Steel*," *MITT., a.d. Kais. Will. Inst. f. Eisenf.*, vol. 14, no. 1, 1932, p. 9.
15. Schulz, E. H., "*Development of High-Grade Structural Steel*," *STAHL UND EISEN*, vol. 48, no. 26, June 28, 1928, p. 849.
16. von Kerpely, K., "*Development of High-Grade Structural Steel*," *STAHL UND EISEN*, vol. 48, no. 33, Aug. 16, 1928, p. 1130.
17. Stogoff, A. F., and Messkin, W. S., "*Cuprous Steels with High Carbon Content*," *A.F.D. EISENHUETTENW.*, vol. 2, no. 5, Nov. 1928, p. 321.
18. Jones, J. A., "*Chromium-Copper Structural Steel*," *JOURNAL, British Iron and Steel Inst.*, vol. 121, no. 1, 1930, p. 209.

19. Nehl, F., "Mechanical Properties of Copper Bearing Steels with Special Regard to Heat Treatment," STAHL UND EISEN, vol. 50, no. 20, May 15, 1930, p. 678.
20. Anonymous, "Copper Steel in the Manufacture of Hardware," CUIVRE ET LAITON, vol. 4, Aug. 30, 1931, p. 387.
21. Kinear, H. B., "Copper Steels," IRON AGE, Sept. 10, 1931, p. 696, Sept. 24, 1931, p. 820.
22. Nehl, F., "Red Brittleness of Copper Steels; Means of Prevention," USINE, vol. 43, no. 31, 1931.
23. Wiessner, "Molybdenum-Copper Steel," BAUTECHNIK, vol. 19, Aug. 26, 1932, p. 472.
25. Anonymous, "The Weldability of Copper Steel," CUIVRE ET LAITON, vol. 5, Oct. 30, 1932, p. 465.
26. Lewis, K. G., "The Properties of Some Copper Bearing Steels," Carnegie Schol. Mem., British Iron and Steel Inst. vol. 21, 1932, p. 87.
27. Cone, E. F., "Copper as an Alloy in Steel and Iron," AMERICAN MACHINIST, vol. 77, Oct. 25, 1933, p. 681.
28. Raedecker, W., "The Influence of a Second Alloying Metal on the Properties of Copper Alloy Steel with Special Regard to Red Brittleness," MIT., Forschung Inst. Ver. Stahlwerke. Dortmund, vol. 3, July, 1933, p. 173.
29. Bain, H. F., "Copper Improves Steel Properties," STEEL, Apr. 16, 1934, p. 32.
30. Miller, H. L., "Copper as an Alloying Element in Steel," METALS AND ALLOYS, vol. 5, Oct. 1934, p. 227.
31. Herzog, E., "Copper Steels," ACIERS SPECIAUX METAUX ET ALLIAGES, Oct. 1934, p. 364.
32. Piskariyev, S., "Production of Copper Bearing Metal at Frunze Plant," STAL, vol. 4, no. 11-12, Nov.-Dec. 1934, p. 27.
33. Zamoruev, G., "Investigation of Copper Steel at the Frunze Plant," STAL, vol. 4, no. 11-12, Nov.-Dec. 1934, p. 58.
34. Anonymous, "R.D.S.—A New Low Alloy High Tensile Steel," IRON AGE, Dec. 6, 1934, p. 32.
35. Bennek, H., "Effect of Very Small Amounts of Copper and Nickel in Carbon Steels," STAHL UND EISEN, vol. 55, Feb. 7, 1935, p. 160.
36. Lorig, C. H., "Copper Alloyed with Steels," METAL PROGRESS, Apr. 1935, p. 53.
37. Epstein, S., and Lorig, C., "Note on the Carburizing of Copper Steels," METALS AND ALLOYS, Apr. 1935, p. 91.
38. Miller, H. L., "Develops New Low-Alloy, High Strength Steel for Transportation Field," STEEL, vol. 96, Apr. 29, 1935, p. 39.
39. Thum, E. E., "Copper Steels," METAL PROGRESS, July 1935, p. 49.
40. Anonymous, "Copper-Molybdenum Steels," INDUSTRY AND WELDING, vol. 8, January 1936, p. 57.
41. Williams, C. E., and Lorig, C. H., "The Role of Copper in Wrought Steels," METALS AND ALLOYS, March 1936, p. 57.
42. Cone, E. F., "The Lincoln-Zephyr Cast Alloy Piston," METALS AND ALLOYS, April, 1936, p. 85.
43. Simpson, K. M., and Bannister, R. T., "Alloys of Copper and Iron," METALS AND ALLOYS, April, 1936, p. 88.
44. Schumacher, E. E., and Souden, A. G., "Some Alloys of Copper and Iron," METALS AND ALLOYS, April, 1936, p. 95.
45. Anonymous, "Copper Steels," MINING AND METALLURGY, March, 1936, p. 130.
46. Finlayson, A., "Low Alloy Steel Castings in Logging and Road Construction," METALS AND ALLOYS, Sept. 1937, p. 239.

47. Copper Development Association, Thames House, Millbank, London, "*Copper in Cast Steel and Iron*" (1937).
48. Sallitt, W. B., "*Copper in Cast Steel*," FOUNDRY TRADE JOURNAL, vol. 58, May 12, 1938, p. 385.
49. Harrison, R., "*Effect of Copper on Some Alloy Steels*," HEAT TREATING AND FORGING, June, 1938, p. 286.
50. Harrison, R., "*Copper in Some Alloy Steels*," METAL PROGRESS, vol. 34, Aug. 1938, p. 130.
51. Harrison, R., "*The Effect of Copper on Some Alloy Steels*," JOURNAL, British Iron and Steel Institute, vol. 137, no. 1, p. 285 (1938).
52. Greenidge, C. T., and Lorig, C. H., "*Properties of Some Copper-Bearing Cast Steels*," TRANSACTIONS, American Foundrymen's Association, vol. 47, p. 229 (1939).
53. Spraragen, W., and Claussen, G. E., "*Welding Copper Steels—a Review*," WELDING JOURNAL, vol. 18, Sept. 1939, p. 289-s.
54. Greenidge, C. T., and Lorig, C. H., "*Copper Steels*," IRON AGE, vol. 145, Feb. 15, 1940, p. 21.
55. Anonymous, "*High Tensile Structural Steels Containing Copper*," E. Houdremont, H. Bennek and H. Neumeister, THE METALLURGIST, Feb. 23, 1940, p. 93.
56. Jackson, J. E., "*Use of Copper in Iron and Steel*," STEEL, vol. 108, May 19, 1941, p. 76.
57. Eberle, F., "*Copper-Bearing Steel for Heavy Fabrication*," METALS AND ALLOYS, vol. 15, Apr. 1942, p. 588, May 1942, p. 758.
58. Faure, M. L., and Friart, M., "*Heavy Forgings of Copper Steel*," METAL PROGRESS, vol. 42, Sept. 1942, p. 456.
59. Anonymous, "*Copper-Bearing Steels for Heavy Fabrication*," METALLURGIA, vol. 26, Sept. 1942, p. 181.
60. Kussman, A., and Scharnow, B., "*On Relationship Between Hardness and Magnetic Properties of Alloys*," V.D.I. ZEIT., vol. 73, no. 38, Sept. 21, 1929, p. 360.
61. Buchholz, H., and Koster, W., "*Temper Hardening of Copper Bearing Steel*," STAHL UND EISEN, vol. 50, no. 20, May 15, 1930, p. 687.
62. Koster, W., "*Age Hardening of Iron Alloys*," Z.F. METALLK. vol. 22, no. 9, Sept. 1930, p. 294.
63. Steinberg, S., and Subow, W., "*Age Hardening of Copper Steel*," IRON AGE, vol. 129, Feb. 4, 1932, p. 330.
64. Anonymous "*Electric Hydrogen Welding of Copper to Steel*," MASCHINENKONSTRUKTEUR, July 10, 1933, no. 13/14.
65. Smith, C. S., and Palmer, E. W., "*The Precipitation Hardening of Copper Steels*," TRANSACTIONS, American Institute of Mining and Metallurgical Engineers, vol. 105, p. 133 (1933).
66. Lueg, E. G., "*Investigation of a Rail Steel with Regard to Hardening by Addition of Copper*," MITT. A.D. FORSCHUNGS AUT. DES G.H.H. KONZERNES, vol. 3, Apr. 1935, p. 199.
67. Russell, H. W., "*Resistance to Damage by Overstress of Precipitation Hardened Copper Steel and Copper Malleable*," METALS AND ALLOYS, Dec. 1936, p. 321.
68. Houdremont, E., Bennek, H., and Neumeister, H., "*The Effect of Certain Low Copper Contents on the Strength of High-Tensile Low-Alloy Structural Steels*," A.F.D. EISENHUETTENWES, vol. 13, no. 3, Sept. 1939, p. 1937.
69. Halley, J. W., "*Precipitation Hardening of Complex Copper Steels*," TRANSACTIONS, American Institute of Mining and Metallurgical Engineers, vol. 140, p. 497 (1940).
70. Halley, J. W., "*Obtaining a 25 Per Cent Strength Increase in Copper-Bearing, High Tensile Steels by Precipitation Hardening*," STEEL, vol. 108, Feb. 17, 1941, p. 92.



71. Anonymous, "The Miscibility Range in the Liquid Iron-Copper Alloys," Z.F. METALLKUNDE, July, 1927, p. 293.
72. Rull, F., "The Effect of Nickel and Silicon on the Miscibility Gap of the Iron-Copper System in the Solid State," Z.F. ANORG. UND ALLG. CHEM., vol. 212, May, 1933, p. 61.
73. Rull, F., "The Effect of Aluminum and Cobalt on the Miscibility Gap of Iron-Copper in the Solid State," Z.F. ANORG. UND ALLG. CHEM., vol. 216, Dec. 29, 1933, p. 133.
74. Vogel, R., and Dannoehl, W., "The Binary Systems Fe-Cu and Fe-Sb," ARCH. F. D. EISENHUTENW., vol. 8, July, 1934, p. 39.
75. Norton, J. P., "Solubility of Copper in Iron and Lattice Changes During Aging," TRANSACTIONS, American Institute of Mining and Metallurgical Engineers, vol. 116, p. 386.
76. Iwase, K., Oramoto, M., and Amemiga, T., "On the Formation of Two Liquid Layers in Copper-Iron Alloys," SCE. REPTS., Tohoku Imp. Un., Apr. 1938, p. 618.
77. Bradley, A. J., Cox, W. C., and Goldschmidt, H. J., "An X-ray Study of the Iron-Copper-Nickel Equilibrium Diagram at Various Temperatures," JOURNAL, British Institute of Metals.
78. Ziegler, N. A., "Thermal Characteristics of Some Low Alloyed Steels," JOURNAL, Western Society of Engineers, vol. 45, no. 6, December 1940, p. 277.
79. Armstrong, T. N., "Properties of Some Cast Alloy Steels," TRANSACTIONS, American Society for Metals, vol. 23, p. 286 (1935).

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DISCUSSION

Presiding: C. W. BRIGGS, Steel Founders' Society of America, Cleveland, Ohio.

CHAIRMAN BRIGGS: Apparently the authors have an idea of using steel of this composition in valves, and I would assume that these valves had high temperature application. Nothing was said about the creep properties of the analyses they investigated. What are the possibilities of Cu-Mo cast steels from the standpoint of creep as compared to a carbon-molybdenum cast steel?

G. A. TIMMONS<sup>1</sup> (written discussion): As our knowledge of the effects of alloying elements in steel is increased it becomes more evident that the ideal steels for welding applications are those which have a "flat" or nearly horizontal hardenability curve in the end-quench hardenability test. Under these circumstances the carbon content is limited by the maximum hardness (or minimum ductility) which may be tolerated in the welded joint. In order to maintain the same mechanical properties as required by service conditions and obtained by steels with higher carbon contents, it is necessary to build up the alloy content of the steel with suitable alloying elements. Alloying elements which form solid solutions in alpha iron may strengthen the low-carbon steels in two ways: (1) by ferrite strengthening, (2) by their effects upon the rates of transformation from austenite to the ferrite-carbide aggregates. The effect accomplished by ferrite strengthening is independent of the heat treatment, whereas the effects upon austenite stability will be dependent upon the heat treatment employed.

Copper as an alloying element for cast steel may improve the mechanical properties of the steel in three ways. In addition to the two effects previously dealt with, steel containing sufficient copper contents may be precipitation hardened. Copper is thus a

<sup>1</sup> Met., Climax Molybdenum Co., Detroit, Mich.

versatile alloying element. It has received considerable attention from research metallurgists, but has not been as widely used by the cast steel industry as one might expect.

The authors have made a valuable contribution to our knowledge of the use of copper in steel castings designed for elevated temperature service. Their complete survey of low-carbon-copper-molybdenum steels provides the necessary data for evaluating the potentialities of copper as an alloying element which will permit a decrease in carbon content, hence an increase in weldability without sacrificing the mechanical properties obtainable in the conventional material; indeed, they have shown that an improvement in these properties may be accomplished along with an increase in weldability.

Since the end-quench hardenability test does not provide a period of cooling comparable to regular normalizing treatments, the authors have submitted a second test consisting of a controlled cooling rate with dilatometric determinations of these transformations from alpha to gamma lattices and the resulting hardnesses and microstructures. This comparatively simple test yields considerable information for the evaluation of the steel being studied.

Attention is drawn to the increased hardness and decreased ductility resulting from tempering the higher molybdenum, higher copper steel at 1300° F. as compared with 1150° F. (Table 3). Molybdenum contents of 0.50 per cent and 1.00 per cent have been shown\* to exhibit a retardation in softening (on hardness vs. tempering temperature curve) at about 1100 to 1150° F. The precipitation hardening of copperbearing steels is usually accomplished at about 900° F. after quenching or normalizing. Is it possible that the combination of the two alloys has increased the temperature at which one or both effects are produced, or is it possible that the copper addition lowered the  $A_{c1}$  temperature to such an extent that tempering at 1300° F. resulted in the formation of some austenite, which on cooling to room temperature transformed to martensite or Widmanstätten structure?

Table 3  
COMPARISON OF PHYSICAL PROPERTIES OF VARIOUS CU-MO STEELS  
DRAWN AT VARIOUS TEMPERATURES

Heat No.	Components, per cent C Mo Cu			Brinell Hardness, Drawing Temp., °F.			Charpy Impact Resistance, Room Temp., ft.-lb.			Charpy Impact Resistance —25° F., ft.-lb.		
							Drawing Temp., °F.			Drawing Temp., °F.		
				1000	1150	1300	1000	1150	1300	1000	1150	1300
14	0.1	1.0	1.0	220	178	184	20.0	29.0	19.5	7.3	18.3	8.3
15	0.1	1.0	1.5	288	220	274	8.0	18.5	16.0	3.3	5.3	6.5
27	0.2	0.5	1.5	247	210	246	12.0	23.0	8.5	5.0	14.8	5.5
29	0.2	1.0	0.5	228	194	251	16.5	29.5	7.8	10.3	19.5	3.8
30	0.2	1.0	1.0	260	210	268	11.8	26.0	8.5	4.0	20.0	5.5
31	0.2	1.0	1.5	270	240	258	11.5	25.3	10.0	4.8	16.0	3.5

MESSRS. ZEIGLER AND MEINHART (*authors' closure*): The authors appreciate the comments by Messrs. Timmons and Briggs.

With reference to Mr. Timmons' remarks, we believe that the dilatometric and metallographic methods employed yield more information for the evaluation of these particular steels than does an end-quench hardenability test.

The increased hardness and decreased ductility found in some of the copper steels subjected to the 1300° F. drawing treatment has been investigated. Figure 16 shows

\*Bain, E. C., "Functions of the Alloying Elements in Steel," A.S.M., 1939.

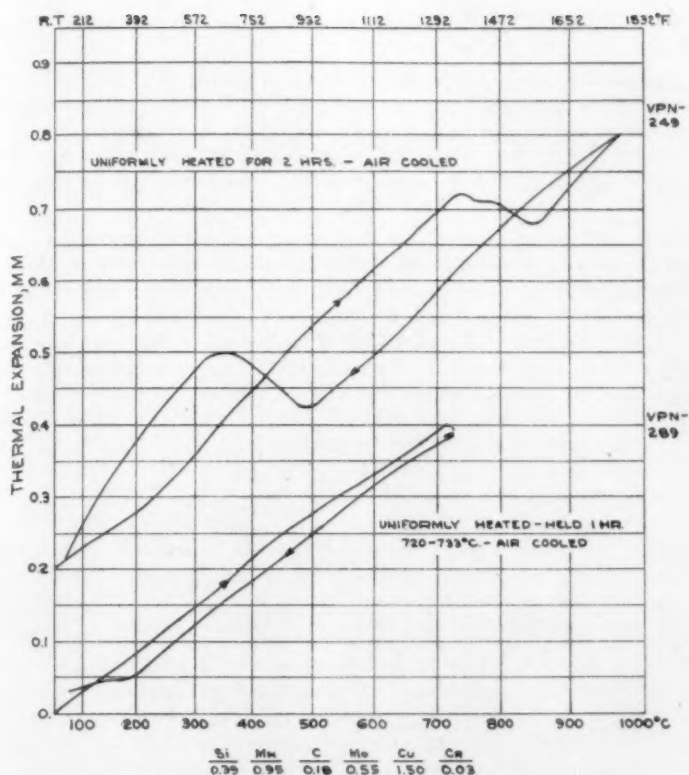


FIG. 16—THERMAL CURVES OF COPPER-MOLYBDENUM STEEL (SERIAL NO. 27).

two dilatometer curves of steel (Serial 27) which contains 0.2 per cent carbon, 0.5 per cent molybdenum and 1.5 per cent copper. The purpose of this test was to determine the effect of drawing just below or at the lower edge of the critical temperature range on heating. A direct comparison is given between a sample uniformly heated to about 970° C. (1778° F.), followed by air cooling, and one uniformly heated to 720 to 733° C. (1328 to 1350° F.), held one hour and air cooled. The latter treatment resulted in a small amount of transformation on heating and a more sharply suppressed transformation on cooling than was obtained with the sample heated well above the critical temperature. Therefore, an additional increase in hardness from 249 to 289 VPN. was produced. Moreover, the test indicated that a slight lag occurs in the beginning of transformation on continuous heating at the uniform rate employed (upper curve, Fig. 16).

In heat treating the test bars, some nonuniformity in furnace temperature quite likely occurred, because of the fairly large mass of bars used and the central location of the thermocouple. Hence the temperature of some of the samples drawn at 1300° F. (704° C.) probably approached the lower edge of the critical range, resulting in the formation of some austenite and consequent suppressed transformation on cooling. This would account for the increased hardness and decreased ductility in these samples, as noted by Mr. Timmons. Microscopic examination indicated that a small amount of the pearlite structure had transformed in a few of the bars. Other samples purposely drawn at 1325

to 1350° F. (720 to 730° C.) definitely show the beginning of transformation in the microstructure.

Slight precipitation hardening evidently occurred during the 1000° F. (540° C.) draw, particularly in the steels containing 1.00 per cent or more copper, as shown by the hardness values obtained before and after this treatment. Increasing the draw temperatures to 1150° F. (620° C.) reduced the hardness in all cases below that of the air cooled samples and produced the most desirable combination of physical properties obtained.

Referring to Mr. Briggs' remarks on the creep properties of these alloys at elevate temperatures, it may be stated that more data and a little better idea of their behavior have been gained since this paper was presented. A conventional cast carbon-molybdenum steel, which has been normalized and drawn, has a creep rate of 1.0 to 1.5 per cent in 10<sup>4</sup> hours at 950° F. (510° C.) and a load of 20,000 psi. Under the same conditions copper-molybdenum steel (Serial 9) containing 0.08 per cent carbon, 0.50 per cent molybdenum and 1.0 per cent copper has a creep rate of 1.5 per cent in 10<sup>4</sup> hours. Another steel (Serial 30) containing 0.20 per cent carbon, 1.0 per cent molybdenum, and 1.0 per cent copper showed slightly better creep resistance than Serial 9 steel for the first few weeks of testing when both were maintained at 850° F. (455° C.). However, the creep rate increased to an average of 3.9 per cent in 10<sup>4</sup> hours at 950° F. (510° C.) with the same load (20,000 psi.) after several months. These observations require further confirmation, but at present it may be tentatively concluded that the creep rate of cast copper-molybdenum steels is comparable to carbon-molybdenum steels provided that the carbon content does not exceed 0.10 per cent. However, even the high carbon copper-molybdenum steel has a creep resistance superior to that of straight carbon steel.

## Some Causes of Test Bar Failures in Navy "G" and "M" Metals

By WM. B. GEORGE\*, CHICAGO

### Abstract

*The cost of not paying attention to the casting of test bars is often expensive to the foundryman. Many things can happen, even with the best of supervision. One of the most unfortunate is that when a test bar fails, the foundryman is unable to diagnose the trouble and prevent it from happening again. It is well known that no two bars will pull exactly alike, even if cast from the same heat, but they should be close enough to properly represent that heat. Almost all specifications give a liberal leeway to cover variations in test bars and allow a second bar to be pulled should the first one fail. If the first test bar fails and the second bar passes, the foundryman does not investigate any further. Here is where he makes his greatest mistake; failing to take advantage of the two specimens and examine them in detail. There is a reason why one of these bars failed, and the chances are better than 90 per cent that it can be searched out and can be prevented from happening again. This paper is prepared for those who are interested in these failures and represents actual cases that have been investigated.*

1. Test bars do not always fail from a single cause, but often from a combination of causes, and this must be kept in mind by the foundryman trying to search out his trouble.

2. In many foundries, test bars have been cast without trouble for years, but, without warning, a series of failures will occur and disappear without the foundryman ever finding out what happened.

3. If we could visit all of our foundries, we would find many different patterns and methods for casting bars. It would be impossible to describe even a small portion of them, for each has been developed to meet an individual situation.

4. The failures are principally the same in all cases, and the major ones are listed here for discussion.

\* R. Lavin & Sons, Inc.

NOTE: This paper was presented at a Brass and Bronze Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

## CAUSES OF TEST BAR FAILURES

*Water Vapor*

5. Water vapor from loose sand grains is about the greatest offender against the making of good test bars (Fig. 1). The water of crystallization of the sand grains themselves is dehydrated when caught in the path of flowing metal. These sand grains generally are torn loose from the top of the sprue when the metal strikes the mold.

6. To overcome this condition, the sprue and runner should be well floured and all excess flour blown off. This gives the skin of the mold the necessary toughness to stop the cutting.

7. Upon close examination of the rough test bar, the cinder residue of these sand grains can be found in the skin of the casting. Sometimes a small hole will appear in the test bar, with the cinder residue in the bottom of it in the form of dust.

*Overheating Metal in a Reducing Atmosphere*

8. When metal is overheated in a furnace which has a reducing atmosphere, hydrogen is absorbed and is released within the casting in inverse proportion to the solidification rate. This is one of the prominent causes of failures. The gas shows up as small, round holes, and can be seen under a 10-power magnifying glass (Fig. 2). The fractured specimen shows a golden color around whatever grain boundaries that might be present.

9. In badly gassed bars, resemblance of grain boundaries disappear.

10. The furnace atmosphere should contain at least 0.3 per cent oxygen to overcome this condition.

*Swab or Water Spray*

11. Metal will not lay to wet surfaces, and sprays or swabbing of the pattern cavity, runner and sprue must be eliminated. Countless test bars have been lost in this way, especially where the molder has a loose pattern.

12. A test bar mold that has been torn by the pattern should not be

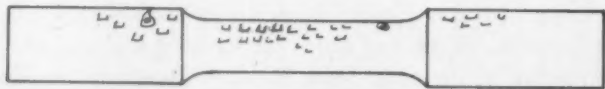


FIG. 1—EFFECT OF WATER VAPOR FROM LOOSE SAND GRAINS ON APPEARANCE OF TEST BAR. ON FRACTURE, THE GRAIN RESEMBLES SUGAR CRYSTALS.

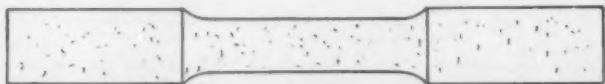


FIG. 2—FINE TO VISIBLE GAS HOLES FOUND IN TEST BAR AS A RESULT OF OVERHEATING THE METAL IN A REDUCING ATMOSPHERE.



patched. The torn sand should be blown off and the spot ground from the casting.

13. Water becomes steam when it comes in contact with molten metal and is temporarily absorbed, separating out at the grain boundaries (Fig. 3). The permeability of the sand must be sufficient to carry steam away from the casting cavity as fast as it is generated.

#### *Overheating Metal in an Oxidizing Atmosphere*

14. The results of overheating the metal in an oxidizing atmosphere are oxide inclusions precipitated out at the grain boundaries. The grain boundaries are weakened by these inclusions and rupture is very pronounced (Fig. 4).

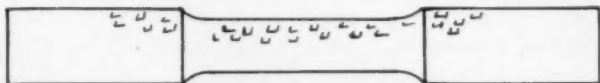


FIG. 3—EFFECT OF SWAB OR WATER SPRAY ON APPEARANCE OF TEST BAR. ON FRACTURE, THE GRAIN RESEMBLES SUGAR CRYSTALS.

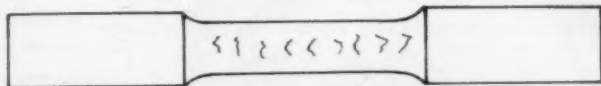


FIG. 4—FINE TO OPEN CRACKS APPEARING IN TEST BAR WHEN SUBJECTED TO TENSILE TEST. THESE CRACKS ARE A RESULT OF OXIDE INCLUSIONS DUE TO METAL BEING OVERHEATED IN AN OXIDIZING ATMOSPHERE.

15. In cases where the metal is badly oxidized, dross inclusions will appear. Where metal must be heated to a high temperature, the oxygen content of the furnace atmosphere should not exceed 1 per cent.

16. Phosphorus additions 5 minutes before pouring are very beneficial in cases of oxidized metal.

#### *Incorrect Pouring Temperatures*

17. There can be no set rule for pouring temperatures for this is governed by the cooling rate within the mold. On green sand molds, for "G" and "M" metals, 2150 to 2100° F. is the practice.

18. To find the proper pouring temperature for a given type of test bar and foundry practice (Fig. 5), heat a batch of metal to 2200° F. and cast it at 50° intervals downward to a minimum temperature of 2050° F. Repeat this procedure four times and then pull the bars, correlating the temperatures against the physical properties obtained.

19. After establishing the temperature at which the best results are obtained, keep the practice within 25° F. plus or minus from this point.



FIG. 5—EFFECT OF POURING TEMPERATURE ON GRAIN SIZE. HIGH POURING TEMPERATURE RESULTS IN LARGE CRYSTALS. LOW POURING TEMPERATURE RESULTS IN APPEARANCE OF DROSS AND COLD SHUTS.

*Additions of Phosphorus at the Wrong Time*

20. In making additions of phosphorus to a bath of molten metal, at least 2 min. (preferably 5 min.:) should elapse before test bars are cast. Should the phosphorus be added just at the pouring time, the reaction will not be completed and probably  $P_2O_5$  or other phosphorus-oxygen gases will be liberated within the casting (Fig. 6).

21. Phosphorus has a three-sided effect on a bath of metal.

- (a) It will reduce oxides when present.
- (b) It will liberate hydrogen gas when present.
- (c) It will absorb oxygen from the atmosphere when there is an excess over that required to reduce the oxides within the bath.

*Shot and Clay Ball Explosions*

22. Clay balls and shot that lodge next to the pattern cavity will explode when they contact the hot metal. To overcome this trouble, the molding sand for test bar faces, gate and runner should be passed through a no. 12 riddle.

23. Flouring the mold helps to dry these balls and always should be practised.

24. Good test bars cannot be expected if the molding sand is loaded with shot and clay balls. The resulting explosions occur in the sprue as well as at the face of the mold, and water from the loosened material combines with the metal in the form of steam (Fig. 7).

*Additions of Zinc at the Wrong Time*

25. As in the case of phosphorus additions, the interval of time allowed for completion of the zinc addition reaction should be at least 2 min. (preferably 5 min.) before casting the test bar.

26. The exact reaction, while not known, is thought by some to be entrapped zinc oxide which does not have time to free itself.

27. At times, the fractures (Fig. 8) appear as if there might be gas present. Zinc additions will liberate gas by the readjustment of the elements within the bath, and here again the interval of time before pouring is necessary.

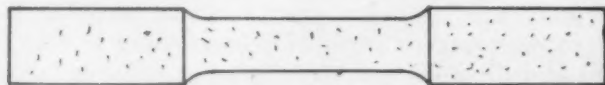


FIG. 6—FINE GAS HOLES IN TEST BAR CASTING AS A RESULT OF INSUFFICIENT TIME ALLOWANCE FOR COMPLETION OF PHOSPHORUS ADDITION REACTION.



FIG. 7—SHOT AND CLAY BALL EXPLOSIONS. THESE APPEAR MOSTLY AS WATER VAPOR WITH OCCASIONAL SAND INCLUSIONS.

*Tight, Wet and Hard-Rammed Molding Sand*

28. Wherever any conditions prevail whereby the metal boils in the mold, the test bar losses will be heavy (Fig. 9).

29. For good results, a sand of 20 permeability with 6.50 per cent moisture is recommended.

30. Hard ramming lowers the permeability, and a 20 permeability sand, by A.F.A. Standard Test, can be lowered to 10 or raised to 50, within the mold, just in the ramming process.

31. Experience has shown that a medium-rammed mold of 30 permeability from a 20 A.F.A. test sand is desirable.

32. Sands with large amounts of silt are not recommended for test bars.

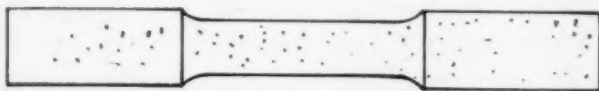


FIG. 8—DEFECTS IN TEST BAR CASTING AS A RESULT OF INSUFFICIENT TIME ALLOWANCE FOR COMPLETION OF ZINC ADDITION REACTION. THESE DEFECTS ARE DIFFICULT TO IDENTIFY AND THE FRACTURE HAS THE APPEARANCE OF AN UNFED CASTING SECTION.

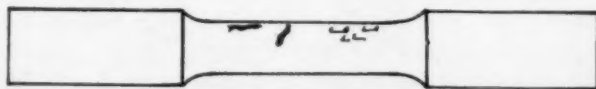


FIG. 9—DEFECTS IN TEST BAR CASTING DUE TO USE OF TIGHT, WET AND HARD-RAMMED MOLDING SAND AND RESULTING IN SLAG, DROSS AND WATER VAPOR.

*Excessive Phosphorus Additions*

33. Where an excess of phosphorus over that required to reduce the oxides of the metal is used, the residual balance will combine with the atmosphere and is believed to produce  $P_2O_5$  and other gases of phosphorus and oxygen (Fig. 10).

34. The phosphorus addition should not exceed 0.05 per cent unless the casting temperature is lowered to compensate for it.

35. When alloys require large amounts of phosphorus, the pouring temperature is lowered close to the freezing range of the alloy.

36. All open sprues and risers should be covered when high phosphorus alloys are cast.

*Hot Short Strain*

37. Hot short cracks (Fig. 11) can come from several causes, one of which is dumping the mold too hot. The test bar molds should not be shaken out

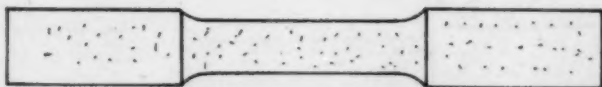


FIG. 10—DEFECTS IN TEST BAR CASTING DUE TO EXCESSIVE PHOSPHORUS ADDITIONS. FINE GAS INCLUSIONS APPEAR IN FRACTURE, SOMETIMES REQUIRING 100 MAGNIFICATIONS FOR VISIBILITY.

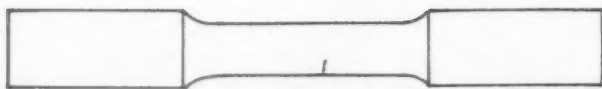


FIG. 11—HOT SHORT CRACK APPEARING AS A DARK FRACTURE ON SIDE OF TEST BAR CASTING AS A RESULT OF HOT SHORT STRAIN.

until 60 min. have elapsed after pouring, and the bars should not be hit with a hammer.

38. The test bars should not be cooled with compressed air or water.

39. The test bars may be sawed free from their gates while warm, but they should cool naturally from that point on.

40. Risers are sometimes placed in the mold in such a position that a strain is put upon the bar. Full length risers, exposed to the air, often are the cause of hot short strain, the top of the riser cooling before the bar and creating a pull.

#### *Water Vapor from Charcoal*

41. When casting test bars, charcoal should never be placed in a ladle and the metal poured on top of it. The charcoal should be kept away from the metal until after the test bars are cast.

42. Charcoal contains water which is liberated into steam which is trapped in the metal should any charcoal become entrapped below the surface of the bath (Fig. 12).

43. There is a proper and an incorrect use of charcoal and, unless the proper use is known, the best policy is to leave it alone.

44. Charcoal should be used only for one purpose, and that is the prevention of oxidation.

#### *Gassing of Metal from Charcoal*

45. Fine gas holes in castings as a result of the use of charcoal is a condition which varies in different foundries (Fig. 13). For those foundries which mix virgin copper or use copper wire for a base, charcoal is advisable, for these bases contain 0.50 per cent cuprus oxide, which should be reduced.

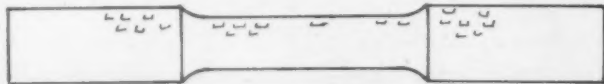


FIG. 12—EFFECT OF WATER VAPOR FROM CHARCOAL ON APPEARANCE OF TEST BAR. ON FRACTURE, GRAIN RESEMBLES SUGAR CRYSTALS.



FIG. 13—FINE GAS HOLES VISIBLE (MAGNIFICATION  $\times 10$ ) IN TEST BAR CASTING DUE TO USE OF CHARCOAL.

46. For those foundries which use ingots with little or no oxide, the use of charcoal is not necessary.

47. Where highly reducing atmospheres are practiced, charcoal is detrimental.

48. Where highly oxidizing atmospheres are present, charcoal is beneficial.

49. When metal has been gassed, charcoal should not be used on the remelting.

50. Charcoal should be used only when it is desirable to prevent oxidation.

#### *Effect of Silicon and Aluminum*

51. Silicon and aluminum are undesirable elements in "G" and "M" metals, and the contents should be kept below 0.005 per cent.

52. In foundries where both silicon-bronze alloys and "G" and "M" metals are cast, great care must be exercised to keep them apart. Silicon combines with lead and it is assumed that it precipitates out at the grain boundaries (Fig. 14).

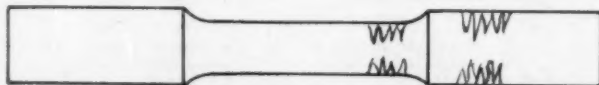


FIG. 14—TEST BAR HAVING APPEARANCE OF HOT SHORT CRACKS DUE TO PRESENCE OF SILICON AND ALUMINUM. FAILURE GENERALLY WILL OCCUR AS A BREAK IN THE NECK OF TEST BAR.

53. Aluminum promotes the growth of large crystals, bringing about weaker properties.

54. Silicon and aluminum are removed with ease by the smelter, but removal is difficult for the foundryman. In electric-arc furnaces, these elements are often produced by molding sand coming between the arcs, the sand being on the gates and castings in the furnace charge.

55. Some operators use barium sulphate to counteract the presence of silicon and aluminum.

#### TEST BAR CASTING PROCEDURE

56. With reference as to what constitutes the proper pouring temperature for a given metal and pattern, the method described in the following paragraphs has been used with success.

57. In Fig. 15 are shown four different test bars, all to be cast within the same mold and using two sprues. Pattern "A" represents a  $\frac{5}{8}$ -in. diameter side-fed bar to be machined to 0.505 in.; pattern "B" represents a  $\frac{5}{8}$ -in. diameter end-fed bar, to be machined to 0.505 in.; pattern "C" represents a 0.505-in. diameter cast-to-size bar, and pattern "D" represents a 0.375-in. diameter cast-to-size bar.

58. A description of an actual test is as follows:

(1) The furnace is regulated so that 0.6 per cent oxygen shows in

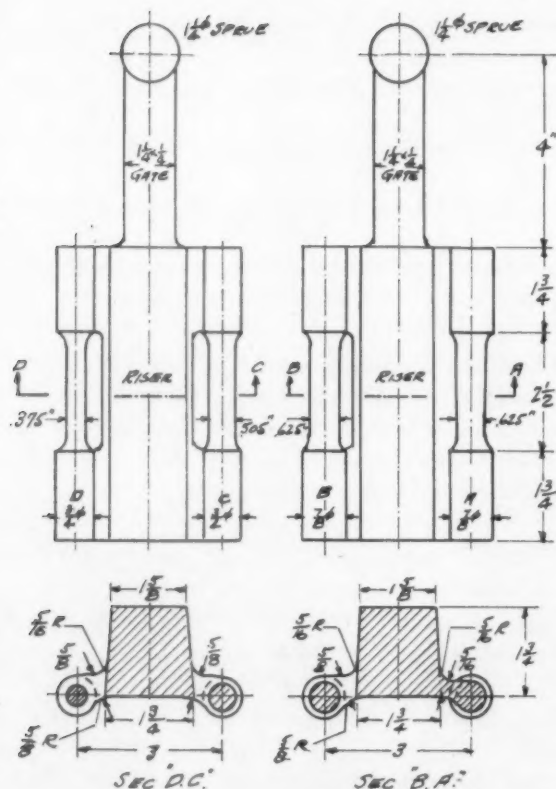


FIG. 15—PLAN AND SECTIONAL VIEWS OF FOUR TEST BARS, ALL CAST IN ONE MOLD WITH TWO SPRUES.

the products of combustion, after the furnace is up to temperature.

- (2) The molding sand is checked and proves to be no. 1 Albany sand with a permeability of 20 and 6.50 per cent moisture.
- (3) Four molds are made to be cast at the following temperatures: 2200, 2150, 2100 and 2050° F.

59. Having melted the metal and cast the bars, the next step is to pull them and correlate their physical properties with the pouring temperatures. The actual results obtained from heats of "G," "M" and 85-5-5 alloys are shown in Tables 1, 2 and 3.

#### SUMMARY

60. It is interesting to note that for these alloys and patterns, 2150° F. is the preferred pouring temperature. Above and below this point, consistency of properties vary.

61. Cast-to-size bars show the best physical properties.



**Table 1**  
MECHANICAL PROPERTIES OF NAVY "G" METAL

Pouring Temperature, ° F.	Test Bar, In.	Yield Point, psi.	Tensile Strength, psi.	Elongation, Per Cent
2200	0.375, Cast-to-size	14800	51900	51.8
	0.505, Cast-to-size	18400	50000	59.1
	0.625, End-feed*	18000	45500	56.0
	0.625, Side-feed*	17500	45500	48.7
2150	0.375, Cast-to-size	14000	50000	64.0
	0.505, Cast-to-size	18000	50000	64.5
	0.625, End-feed*	18500	45000	54.5
	0.625, Side-feed*	18000	45000	49.0
2100	0.375, Cast-to-size	14500	51900	63.0
	0.505, Cast-to-size	18500	50500	67.0
	0.625, End-feed*	18000	46000	56.5
	0.625, Side-feed*	18000	45500	54.0
2050	0.375, Cast-to-size	22400	53000	37.5
	0.505, Cast-to-size	19000	53000	60.0
	0.625, End-feed*	18500	47000	61.2
	0.625, Side-feed*	18000	46500	45.0

*Analysis, per cent*—Cu 88.34, Sn 7.62, Pb 0.17, Fe 0.06, Sb 0.02, Ni Trace, Si 0.00, S 0.011, Zn Remainder.

**Table 2**  
MECHANICAL PROPERTIES OF NAVY "M" METAL

Pouring Temperature, ° F.	Test Bar, In.	Yield Point, psi.	Tensile Strength, psi.	Elongation, Per Cent
2200	0.375, Cast-to-size	19200	45500	45.0
	0.505, Cast-to-size	21000	47900	45.8
	0.625, End-feed*	18500	40500	39.5
	0.625, Side-feed*	16000	39500	36.0
2150	0.375, Cast-to-size	21800	50000	54.8
	0.505, Cast-to-size	19500	46100	51.7
	0.625, End-feed*	16000	42000	44.0
	0.625, Side-feed*	15000	42000	42.5
2100	0.375, Cast-to-size	19000	46000	40.5
	0.505, Cast-to-size	19700	44100	40.0
	0.625, End-feed*	16000	41000	46.5
	0.625, Side-feed*	16500	40000	36.5
2050	0.375, Cast-to-size	21000	52100	42.5
	0.505, Cast-to-size	21000**	41900**	30.0**
	0.625, End-feed*	18000	42500	42.2
	0.625, Side-feed*	18000	44000	45.5

*Analysis, per cent*—Cu 87.07, Sn 6.16, Pb 1.69, Fe 0.15, Sb 0.06, Ni 0.73, Si 0.00, S 0.039, Zn Remainder.

\*0.625-in. is the cast diameter which is machined to 0.505-in.

\*\*Dross inclusion.

**Table 3**  
MECHANICAL PROPERTIES OF 85-5-5-5 ALLOY

<i>Pouring Temperature, ° F.</i>	<i>Test Bar, In.</i>	<i>Yield Point, psi.</i>	<i>Tensile Strength, psi.</i>	<i>Elongation, Per Cent</i>
2200	0.375, Cast-to-size	11200	36600	33.5
	0.505, Cast-to-size	14400	34600	25.0
	0.625, End-feed*	15500	34000	27.7
	0.625, Side-feed*	16000	32500	19.0
2150	0.375, Cast-to-size	13600	41900	34.0
	0.505, Cast-to-size	17200	39200	36.8
	0.625, End-feed*	15500	36500	31.5
	0.625, Side-feed*	14000	36500	36.7
2100	0.375, Cast-to-size	15200	38900	28.5
	0.505, Cast-to-size	16500	40000	36.2
	0.625, End-feed*	13100	36600	31.5
	0.625, Side-feed*	15800	35800	35.0
2050	0.375, Cast-to-size	Cold shut	Cold shut	Cold shut
	0.505, Cast-to-size	Cold shut	Cold shut	Cold shut
	0.625, End-feed*	Cold shut	Cold shut	Cold shut
	0.625, Side-feed*	15000	38500	31.50

*Analysis, per cent*—Cu 84.59, Sn 4.53, Pb 4.58, Fe 0.20, Sb 0.12, Ni 0.61, Si 0.00, S 0.034, Zn Remainder.

62. On an average, end-fed bars exceed the side-fed bars in elongation.

63. The author believes that this method of testing metal, along with the pattern used, is worthy of any foundryman's time in determining what is best for his particular set-up.

64. Where dry sand molds are used, the temperatures for checking are 2100, 2050, 2000 and 1950° F.

65. In checking physical properties on high phosphorus alloys, exceedingly low temperatures are required, the lowest of which is close to the freezing point of the alloy.

### DISCUSSION

*Presiding:* W. ROMANOFF, H. Kramer & Co., Chicago, Ill.

*Co-Chairman:* G. K. DREHER, Ampco-Metal, Inc., Milwaukee, Wis.

CHAIRMAN ROMANOFF: During peace-time, as you gentlemen know, there were very few foundries that poured test bars, but today, there are very few foundries that do not. Test bars are required on practically all of the Government work being made today.

B. A. MILLER<sup>1</sup>: Is the increase in strength of the cast-to-size test bars caused by the quick cooling rate or it is caused by the skin of the casting?

MR. GEORGE: I would say that it is due to both. We know that an unmachined cast 5/8-in. diameter bar has a greater strength per sq. in. than it has after machining. We

\*0.625-in. is the cast diameter which is machined to 0.505-in.

<sup>1</sup> Baldwin Locomotive Works, Cramp Brass & Iron Foundries Div., Philadelphia, Pa.

know that, upon fracture, the skin shows a much denser structure. There is more strength in the skin than there is in the center of the bar.

MR. MILLER: What increase in physical properties would you expect in cast-to-size versus machined bars?

MR. GEORGE: At least a 10 per cent increase in physical properties in cast-to-size bars over machined bars, that is, removing 1/16-in. of skin. Of course, if machined bars are cast close to size, that 10 per cent gap begins to close up.

MR. MILLER: Is there any difference between test bars which have been strain relieved and those which have not?

MR. GEORGE: Yes. Test bars which have been strain relieved will average 5 per cent greater physical properties than those which have not.

MR. MILLER: Have the test bars shown on your tables been strain relieved?

MR. GEORGE: No. It takes from one to 30 days to strain relieve a test bar. The strain relieving is a process that goes on in the bar after the skin has been removed. We notice that bars which are machined and then shipped some distance to be pulled have slightly higher physical properties due to this stress relieving.

G. P. HALLIWELL<sup>2</sup>: In paragraph 9, what is meant by the statement that in badly gassed bars, resemblance of grain boundaries disappear. All metal has crystals and it would have to show grain boundaries.

MR. GEORGE: When the gas is liberated it separates out of the grain boundaries and breaks up these boundaries, and we have the appearance of the continuation of gas holes instead of grain boundaries. In other words, it looks like the continuation of small marbles, we will say, in reverse. The boundaries have disappeared. Grain boundaries are very pronounced in oxidized metal, and as we begin to pass from the oxidized state to the gas state, they start disappearing.

MR. HALLIWELL: That is, the surface appears to be smoothed over on these boundaries that disappear, as if the metal had just been melted?

MR. GEORGE: No, I would say that the boundaries were broken up or distorted by the gases.

MR. HALLIWELL: Are the results shown at the 2150° F. temperature in Table I an average of 200 heats?

MR. GEORGE: No, this is one heat, just as it came.

MR. HALLIWELL: Then I do not believe that you have a fair picture.

MR. GEORGE: The idea of this paper was to bring out the defects in test bars, not the physical properties.

MR. HALLIWELL: In the 0.505-in. cast-to-size bar at 2050° F., you have almost as good properties as in any bar cast in the whole set, 53,000 psi. tensile strength and 60 per cent ductility. On the basis of that, if I were a foundryman and was looking for a good temperature at which to pour, I would pour it at that temperature.

MR. GEORGE: As I said before, we could get abnormal properties above and below 2150° F., but they are not consistent.

MR. HALLIWELL: That is what I want to bring out. If it is only one bar, that is an entirely different proposition.

MR. GEORGE: All of these bars are from the same heat.

MR. HALLIWELL: There is another thing that I believe should be clarified because it has come up so many times, and that is the subject of yield strength and yield point. Many of us have had arguments on this question, and my idea is that there is no such thing as a yield point in brass and bronze. What do you mean by yield point?

MR. GEORGE: I agree with you there. Of course, this yield was taken in the cus-

<sup>2</sup> H. Kramer & Co., Chicago, Ill.

tomary way with a pair of dividers. The paper was not to bring out the physical properties of metal. It is a discussion for the making of test bars. It was to bring out the causes of the bar failures.

MR. HALLIWELL: No matter what the paper is intended for, I believe that we should have a clarification of some of the points that are controversial.

MR. GEORGE: We could clarify it to such an extent that it would be voluminous.

D. F. O'CONNOR<sup>3</sup>: Did you use a crucible for melting in these tests?

MR. GEORGE: Yes.

MR. O'CONNOR: Many foundrymen pour the metal from the melting furnace into a portable ladle and, in my opinion, it is difficult to determine whether some of the defects that appear in the test bar may not be caused by the ladle lining or the preheating of the ladle.

MR. GEORGE: Yes, we know that metal can be gassed from green ladles.

MR. O'CONNOR: It has been my experience that to obtain a good, sound test bar we must liberate the gas from the mold. Therefore, where the wedge-shaped riser comes off the bar, do you believe that the strain set up in cooling would offset the defects that would be caused by the liberation of the gas through that head?

MR. GEORGE: That is quite a technical question. We do know that when the top of the head solidifies on such a bar it is in a state of strain, and that, if it solidifies while the metal in the bar is still hot, it does send a strain back through the bar.

MR. O'CONNOR: You have not mentioned the rate of pouring of the test bar. Possibly, some of the defects in test bars may be caused by trapped gases if the metal flows into the mold with such velocity that it does not permit these gases to escape. Then it is a question of whether we will get better results by having the open head, permitting the gases to escape, or of pouring at the proper temperature so that strains will not be set up.

MR. GEORGE: The permeability of the sand takes care of gases.

MR. O'CONNOR: Would they not pass out more readily through an open head?

MR. GEORGE: I believe that the closed head would be preferable, letting the gases pass through the sand.

J. G. WEBER<sup>4</sup>: Are the  $\frac{3}{8}$ -in. and 0.505-in. test bars cast to size? Are you actually casting to micrometer size?

MR. GEORGE: We turn the pattern to micrometer dimension and cast to size, and use that area for testing the physical properties. A  $\frac{1}{2}$ -in. bar does not come out 0.505 in. in a casting. As a rule, it comes out a few thousandths larger.

H. R. KING<sup>5</sup>: Do you find any bad effects from cutting off test bars with an abrasive cut-off wheel rather than sawing them off?

MR. GEORGE: No.

MR. KING: If you find 2000° F. to be the proper pouring temperature for test bars in dry sand molds and wish to pour the castings at 2100° F. to get good castings, how do you accomplish it?

MR. GEORGE: We would have to pour the casting first and the test bar from the last of the pot.

MEMBER: Do you use flour on the sprue?

MR. GEORGE: Yes.

MEMBER: How would silver lead behave on the sprue?

MR. GEORGE: I imagine that some would wash through. I do not recommend silver lead on test bars. We use flour entirely.

<sup>3</sup> Walworth Co., Inc., Greensburg, Pa.

<sup>4</sup> Ampco Metal, Inc., Milwaukee, Wis.

<sup>5</sup> Metal & Alloy Specialties Co., Inc., Buffalo, N. Y.

HAROLD J. ROAST<sup>6</sup>: As to the question of test bars, I do not agree that it would be voluminous to elucidate the matter. In any problem, we can give an X number or an infinity number to things we can not and should not do, but it does not follow that we have to give anything like that number to the things that enable us to solve the problem. It is because of that we have, in our particular company, adopted the keel block.

Now in the first place, it is not my keel block. It was originated many years ago and still has a great many adherents.

The first objection to the keel block, I am told, is that it takes from 35 to 40 lb. of metal. That assumes, therefore, that when you are making large castings, say from 1000 to 6000 or 8000 lb., that you always melt the metal within 40 lb. You generally put the excess metal into ingots. It is more practical and more profitable to put it into test bars.

Then it also assumes that the test bar is not attached to the casting. Now during the last war, as well as this, we have fought out the question of that point with the English, American, French and Canadian specifying authorities and we have never attached a test bar to a casting. We must remember that a test bar has one purpose only, and that is not to tell us the strength of the casting but the quality of the metal which went into it.

From there, we logically go to the fact that it must be of a form to give us the best quality of the metal, metal as analogous to the casting as possible. From there on, to me it is logical to say that cast-to-size bars do not fulfill those conditions. I have found that inspectors would frequently object because they say, "We want this test bar attached to the casting. We think we are going to get a result similar to the casting."

Now we have to admit that a 0.505-in. cast-to-size bar certainly does not represent a big casting as well as a casting like the keel block, which has this massive metal to keep it hot and where the cross section of the square bar is  $1\frac{1}{4}$  in. In the case of the keel block you may safely say to an inspector, "That is of sufficient size to really represent the strength of the casting, where the conditions of the casting simulate the test bar, which of course is not very often." Any casting has, at least, from three to six extremely different strengths at different points.

In regard to the question of charcoal, I agree with Mr. George that it is a dangerous thing to handle, whereas it formerly was looked upon as the cure-all. However, there are conditions in which it is as good as he says as long as we have it, say, on the top of the cold ingot metal and the charcoal is red hot and dry before the metal reaches the red-hot point where it will start to absorb.

Of course, if you have gas in the metal, not only should you not cover it with charcoal but you should not cover it with anything if you want the gas to get out.

Personally, and I took the same exception to a report of the Test Bar Committee in England, I do not believe that the figures given in Table I are at all as close as they should be for the same metal cast at the same temperature. In Table I, under 2150° F. are shown 14,000 and 18,000 psi. yield points. The beauty of the keel block is that I have yet to find any notable difference, let us say, within 1000 psi., in any one of the three bars.

Now we come to the contentious yield point. I agree with Mr. Halliwell when he says that he does not believe in the term. Obviously you must define it. We have used two yield points. One is the extensometer reading. The extensometer is attached to the bar, and we pull the bar with the load on until we have reached 0.01-in. extension. That, at least, is a positive thing that can be followed in one place and another throughout the country. If we take the scribe test, we will find that the scribe some-

<sup>6</sup> Canadian Bronze Co., Montreal, P. Q., Canada.



times gives very astonishing results, always higher, but sometimes 3000 to 4000 lb. higher on a bar going say 45,000 or 50,000 psi. That is obviously the reason why foundrymen prefer the scribe test.

MEMBER: Do you find any variation in pouring in warm dry sand as against cold dry sand?

MR. GEORGE: Yes. There is danger in pouring in cold dry sand because there is a certain amount of water vapor present. If the cores are warm, we seem to get the best results. Of course, we know that if the cores are very hot, then it is the same as adding more temperature to the metal. There is a difference.

M. C. ROWLAND: We pour Navy "G" metal and we also machine the bars and give them a final grinding operation. We pour two molds with two test bars in each, and then take one bar from each mold to test, and we have found that, at times, these bars will fail. They will have low strength and very low elongation. If we take two test bars, one from each mold, and have them carefully machined, the results are always good. We have never had a failure when we had the bars carefully machined. We assume that since the fracture is discolored, the bars were burned during the grinding operation. We have attempted to produce the burned condition in machined bars by heavy grinding, but were unable to do so. Have you ever encountered this problem?

MR. GEORGE: I have not seen that condition, but I have found that where two bars are cast in a mold and the cavity of one pattern is swabbed, there is a loss of physical properties in the bar from the swabbing and the other bar would be up to standard.

MR. HALLIWELL: I agree with most everything that Mr. Roast has said here, but many of the foundries today are not making 1000 to 8000-lb. castings; they are making smaller castings and using 200-lb. pots. Obviously, 40 or 50 lb. taken for test bars from a small heat constitutes a relatively large amount of metal. Do you use the same test bar for the small heats?

MR. ROAST: Yes, we use the same test bar. I agree that if you must take a test bar out of each crucible, something would have to be done about it. What we did was to arrange with the inspectors to take spot checks of so many crucible heats. If you can not do that, then you will have to decide whether the casting is so critical and the test bar from it is so critical that you should use the bar that will give the best and most reliable results. But I would be inclined to use a cast-to-size bar if I had to make a test bar from each crucible heat.

MR. KING: Mr. George, will you summarize the means used to obtain good test bars?

MR. GEORGE: The use of a good, clean molding sand, having a permeability of about 30 in the mold. The sand must be free of all shot and clay balls. The mold, sprue and runner should be well cleaned, floured, and all excess flour blown off.

In pouring the bar, care must be taken that the metal does not strike the weight on top of the mold, or does not cut the zinc oxide off the front of the weight which has accumulated from previous heats.

We believe that the method of gating shown (Fig. 15) is an economical one and reduces the chance of metal washing in the mold. If any dross should come through the sprue, it will probably go into the riser and not into the casting.

In the melting of metal for test bars, the furnace should contain from 0.3 to 0.6 per cent of oxygen and the metal should never get beyond the plastic stage until the total charge is in the furnace. The metal is then brought up to the temperature required to cast the bar, or not more than 100° F. over the temperature at which it is intended to cast the bar, in which case it is then allowed to cool to the proper temperature.

<sup>†</sup> General Electric Co., Schenectady, N. Y.



# The Rate of Spheroidization and the Physical Properties of Pearlitic Malleable Iron After Isothermal Quenching

By WALTER H. BRUCKNER\*, URBANA, ILL., AND JUN HINO\*\*, ROCKFORD, ILL.

## Abstract

*This paper presents data concerning investigations made on the feasibility of reducing the heating cycle required for spheroidization of malleable iron. The investigations included isothermal quenching at temperatures of 1200, 1100, 1000, 900 and 600° F. Photomicrographs are included to show the malleable irons investigated "as received," as isothermally quenched and at various stages of spheroidization.*

## INTRODUCTION

1. The pearlitic malleable type irons studied are produced by processing white iron castings suitably balanced as to chemical content to give an end product containing nodular graphite and spheroidal carbides dispersed in a matrix of ferrite. The present practice in processing the white iron castings consists of two stages of heating as follows:

- (1) The first stage anneal in which the white iron is heated to around 1700° F. and held for a sufficient time to decompose all massive cementite to nodular graphite. The charge is then removed from the furnace and allowed to cool in air.
- (2) The second stage in which the pearlite resulting from the transformation of austenite remaining after the first stage anneal is spheroidized by heating at 1280° F. for 30 to 40 hr.

2. The white iron castings are usually packed in boxes to minimize decarburization during first stage anneal, thus, when a car-full of such boxes is removed from the furnace after first stage anneal, their cooling rate in air is low. The low rate of cooling causes the austenite to transform to coarse, lamellar pearlite which is reluctant to spheroidize at 1280° F. The industry desired to reduce the 30- to 40-hr. heating cycle now required for spheroidization to one of shorter duration. It was suggested by D. P. Forbes, President of Gunite Foundries Corporation, that an isothermal quench of the austenite after first stage anneal would produce a fine pearlite which could easily be spheroidized.

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3. Some work on this subject was previously carried out in the Department of Mining and Metallurgical Engineering by C. S. Nielsen, B.S. 1940, as a partial requirement for a degree in metallurgical engineering. The data obtained by Nielsen indicated that the fine pearlite resulting from isothermal decomposition of the austenite could be spheroidized at 1280° F. in a substantially shorter time than the coarse pearlite resulting from industrial processing. Nielsen's data was reported by H. L. Walker in discussion of R. J. Cowan's paper\* presented before A.F.A. in 1940. The effects of the isothermal quenching and spheroidization on the physical properties and the response of irons of differing chemical contents could not be surveyed in the time available for a senior thesis.

4. The research herein reported was made the subject of a master's thesis by the junior author, Jun Hino, under the senior author's direction, in the Department of Mining and Metallurgical Engineering, of which Professor H. L. Walker is the head. The work was conducted as a project of the Engineering Experiment Station, of which Dean M. L. Enger is the director.

5. The large number of specimens required for the research were supplied by the Gunité Foundries Corporation through D. P. Forbes and by the Eastern Malleable Iron Company through J. A. Durr, Technical Director. The assistance of P. A. Paulson and G. K. Minert, Metallurgist and Chemist, respectively, of the Gunité Foundries Corporation in arranging for the casting and first stage annealing of the test bars is gratefully acknowledged.

#### MATERIALS

6. All of the irons studied were supplied by the foundry in the form of standard malleable iron tensile bars with a 2½-in. length between shoulders and approximately ⅝-in. diameter in the gage length of 2 in. It was requested that the foundry supply test bars of the above form which had been given the first stage anneal to break up the massive cementite. The specimens, however, had been given the first stage anneal, and in addition were spheroidized at the foundry before shipment.

7. The analyses of the irons included in the paper are given in Table 1. It will be noted that fair checks of total carbon content were obtained for all analyses except GZ4 in which considerable variation occurred. One of the foundries reported that the following procedure was employed in melting and casting the irons:

"The cold charge in the air furnace consisted of approximately 30 per cent hard iron, 10 per cent malleable scrap, 35 per cent pig iron, and 10 per cent steel scrap. To this was added 15 per cent of iron from the cupola consisting of 70 per cent hard iron scrap plus 30 per cent pig iron. The steel was made from steel scrap, and enough silvery pig or silicon to bring out 2.50 per cent silicon from the cupola; blown in the converter and deoxidized with ferro-manganese,

\*Cowan, R. J., "Heat Treatment of Malleable Iron," TRANSACTIONS, American Foundrymen's Association, vol. 46, pp. 293-297 (1940).

Table 1  
ANALYSES OF PEARLITIC MALLEABLE IRONS

Grade No.	Per Cent				
	T.C.	Mn	Si	P	S
GZ1	1.94*	0.73	0.86	....	....
	1.98	...	...	0.148	0.070
GZ2	2.18*	0.73	0.88	....	....
	2.16	...	...	0.113	0.071
GZ3	2.12*	0.76	0.91	....	....
	1.98	...	...	0.148	0.071
GZ4	1.79*	0.76	0.96	....	....
	1.14	...	...	0.066	0.068
GZ5	2.10*	0.70	1.00	....	....
	2.16	...	...	0.064	0.072
GZ6	2.03	...	...	....	....
	1.85*	0.94	0.89	....	....
GZ7	1.96	...	...	0.142	0.080
	2.08*	1.14	0.80	....	....
EZ1	2.08	...	...	0.132	0.076
	2.50*	0.75-0.80	1.11	....	....

\*Denotes use of sample of white iron for analysis, all others were from iron after first stage anneal.

ferro-silicon, and aluminum. The steel was added to the air-furnace iron in proportions calculated to get the desired carbon from 2.30 per cent carbon, air-furnace iron, and 0.30 per cent carbon steel."

8. The steel and air-furnace iron were not weighed to determine their exact amounts before mixing and it was, therefore, not always possible for the foundry to make a close approach to the desired chemistry. The wide variation in the total carbon reported on separate samples of grade GZ4 in Table 1 may be indicative of insufficient mixing of the iron and steel before pouring the tensile, bar castings.

#### METHODS AND PROCEDURE

9. It was decided that the studies on the isothermal decomposition of the austenite remaining after first stage anneal should be made on the austenite existing at the temperature of annealing. Therefore, all of the irons were heated to 1700° F. for re-austenitizing prior to cooling at various rates or to various isothermal transformation temperatures.

10. A dilation-time study was made of the transformation of austenite quenched from 1700° F. in lead or lead-bismuth at temperatures in the range of 1200 to 600° F. The study was made with the same type of dilatometer as described by Davenport and Bain†. The end of the transformation was determined from the peak of the time-elongation curves for specimens approximately 3 in. long, ¼ in. wide and 1/16 in. thick. All of the irons given in Table 1, with the exception of the GZ7 iron, were thus studied, and provided the data required for isothermally quenching the tensile bars.

11. The GZ1 and EZ1 tensile bars were initially used for studies of physical

†Davenport, E. S., and Bain, E. C., "Transformation of Austenite at Constant Subcritical Temperatures," TRANSACTIONS, A.I.M.E., vol. 90, p. 117 (1930).

properties and were austenitized at 1700° F. The tensile specimens were quenched in lead or lead-bismuth at temperatures in the range of 1200 to 600° F. The tensile bars were held in the quenching pot for 150 per cent of the time required for complete transformation as previously indicated from the dilatometer studies. Two bars of each of the two grades of iron were cooled from 1700° F. as follows: (1) in the furnace, (2) in still air, (3) in lead at 1200° F., (4) in lead at 1100° F., (5) in lead at 1000° F., (6) in lead at 900° F., (7) in lead at 800° F., and (8) in lead-bismuth at 600° F. Tensile tests made on the bars in the as-transformed condition, without spheroidizing, indicated that similar properties were exhibited by irons cooled as in (2), (3), (4) and (5) above. A survey of the microstructure of the bars after tensile tests had been made showed that the lamellar pearlite resulting from cooling as in conditions (2) to (5) were not greatly different. It was, therefore, desirable to establish the cooling rate and austenite transformation temperature for all conditions of cooling.

12. A tensile specimen was provided with a central drilled hole into which a sheathed thermocouple of 0.10-in. diameter platinum, platinum plus 10 per cent rhodium thermocouple wire was inserted as shown in Fig. 1. The thermocouple was attached to a 2-sec. recorder which gave an automatic record of the instantaneous temperatures from the time of quenching at a temperature of 1700° F. to the time when transformation had been completed and the recorder was stopped. Figure 2 shows the cooling curves obtained by plotting the data on the recorder chart for all conditions of cooling, except (1) furnace cooling. From the data compared in Fig. 2 and the results of examination of the microstructure, it appeared to be desirable to limit the study of physical properties to tensile specimens cooled from 1700° F. as follows:

Series A, furnace cooled

Series B, air cooled

Series C, quenched in lead at 1000° F.

Series D, quenched in lead at 800° F.

Series E, quenched in lead-bismuth at 600° F.

13. Tensile tests were made on specimens of all grades of iron in the as-transformed condition, series A, B, C, and D without spheroidization. Similar tests were attempted for irons in series E, but due to their extreme brittleness, the tensile bars broke in the grip ends. On completion of the tensile tests, the specimens were cut up into a number of half-round disks, approximately ¼-in. thick, which were heated in cast iron chips to 1280° F. in order to study the rate of spheroidization. The progress of spheroidization at 1280° F. was determined from the microstructure of specimens removed from the furnace after they had been maintained at furnace temperature for the following intervals (in hr.): ½, 1, 3, 5, 10, 17, 24, 36, 48, and 68. Hardness tests were also made on the specimens removed from the furnace at the intervals previously shown.

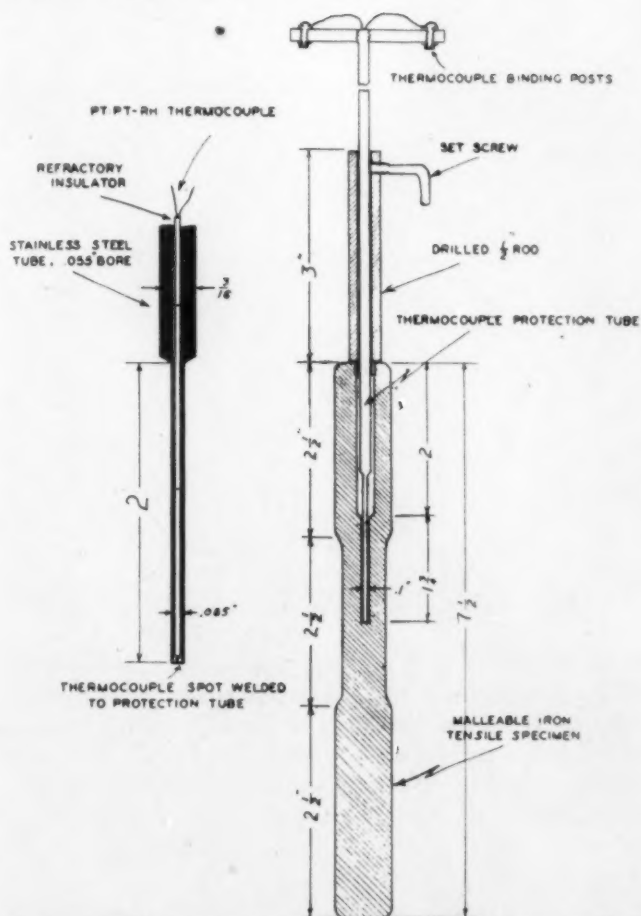


FIG. 1—CONSTRUCTION OF THERMOCOUPLE FOR OBTAINING COOLING CURVES OF TENSILE BARS.

14. The micrographic survey of the progress of spheroidization showed that complete spheroidization had been attained in 10 hr. for all specimens, except those that were furnace cooled. Two tensile specimens from each series from *A* to *E* were then spheroidized for 10 hr. at 1280° F. and furnace cooled. Tensile tests were made on the specimens but their ductility was, in general, quite low, therefore, another set of two bars of each of series *A* to *E* was spheroidized at 1280° F. for 36 hr., cooled in the furnace, and tested for tensile properties. Two bars of each analysis in series *E* were spheroidized for 5 hr. at 1280° F., and tested for tensile properties since the specimens, that were heated for 5 hr. at 1280° F., appeared to have attained complete spheroidization.

#### DATA OBTAINED

15. The "as received" microstructures of all of the irons included in the

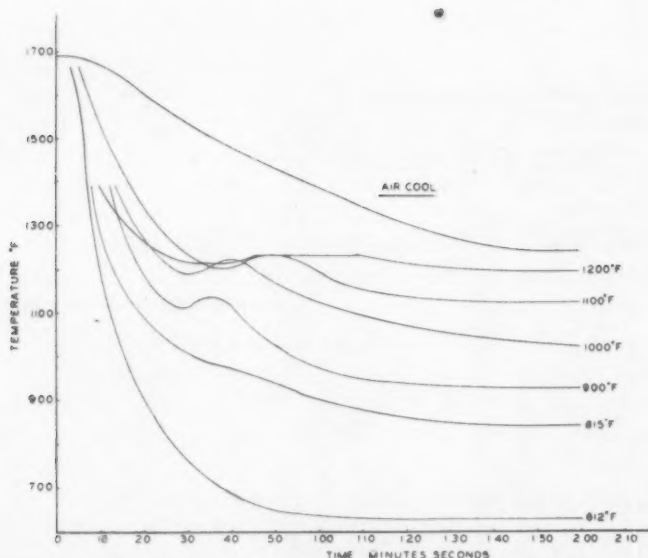


FIG. 2—COOLING CURVES OF TENSILE BARS COOLED FROM 1700° F. USING THE THERMOCOUPLE SHOWN IN FIG. 1 ATTACHED TO A 2 SEC. RECORDER TO OBTAIN THE DATA.

research are shown in Figs. 3 to 6. The distribution of the nodular graphite is shown in the micrographs at 50x and the condition of the combined carbon is shown at 500x. It will be noted that all of the micrographs except that of GZ7 have a large percentage of spheroidized carbides which resulted from the spheroidizing treatment in the foundry. The specimen GZ7 is the only one which had a definitely lamellar structure. The latter specimen had been subjected to a first stage anneal, in vacuum, and furnace cooled in the laboratory from 1700° F.

16. The effect of increasing manganese (Table 1) is shown in the sequence of micrographs for irons GZ5, GZ3 and GZ6 (Figs. 5 and 6). The specimen GZ5 appeared to have been completely spheroidized while GZ3 and GZ6 showed a residual lamellar structure. The GZ6 specimen which had the highest manganese content had a considerable number of massive carbide particles which were not broken down during the first stage anneal. This sequence of micrographs illustrates the potent effect of manganese in stabilizing the carbides.

17. The change in the size and distribution of the nodular graphite due to an increase in the total carbon content (Table 1) is illustrated in the sequence of micrographs for irons GZ2, GZ3, and GZ4 as shown in Fig. 5. The extent of dispersion and the size of the graphite nodules decreases in the order named. In addition, the spheroidal condition of the carbides in specimen GZ2 reflects the slightly lower manganese content of this analysis.

18. The rate of isothermal decomposition of all of the various grades of



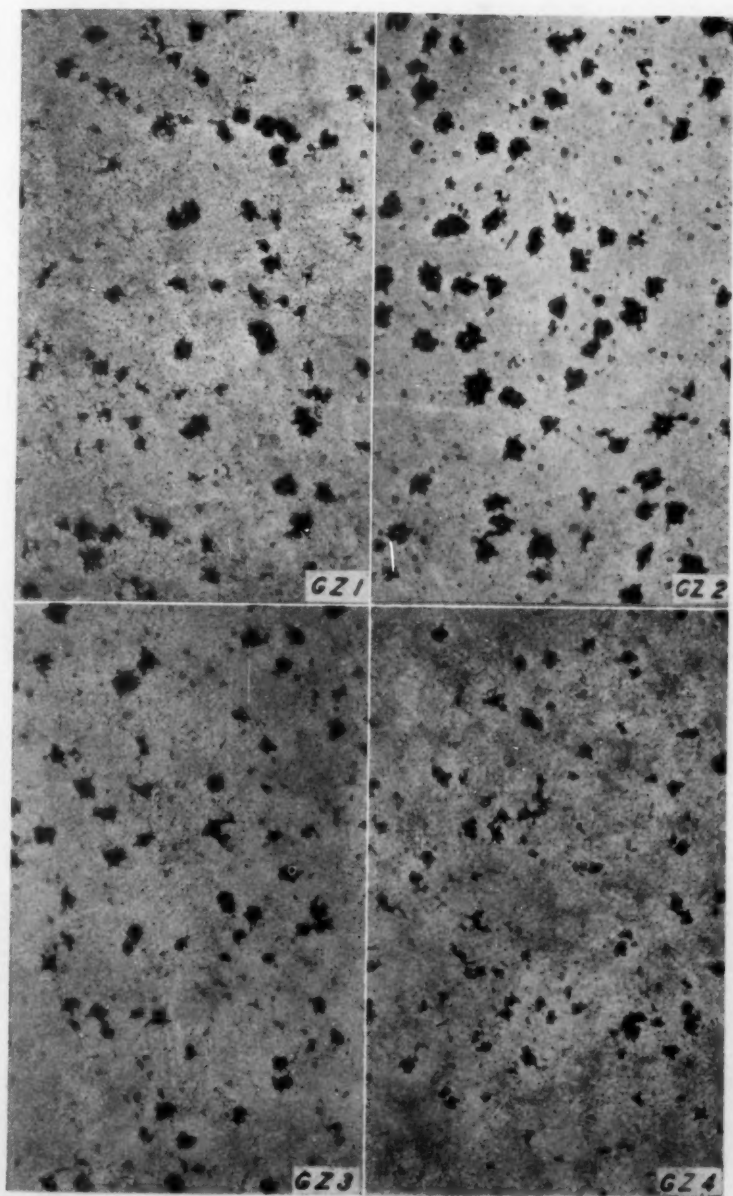


FIG. 3—PHOTOMICROGRAPHS OF MALLEABLE IRONS GZ1 TO GZ4 "AS RECEIVED". MAGNIFICATION 50X.

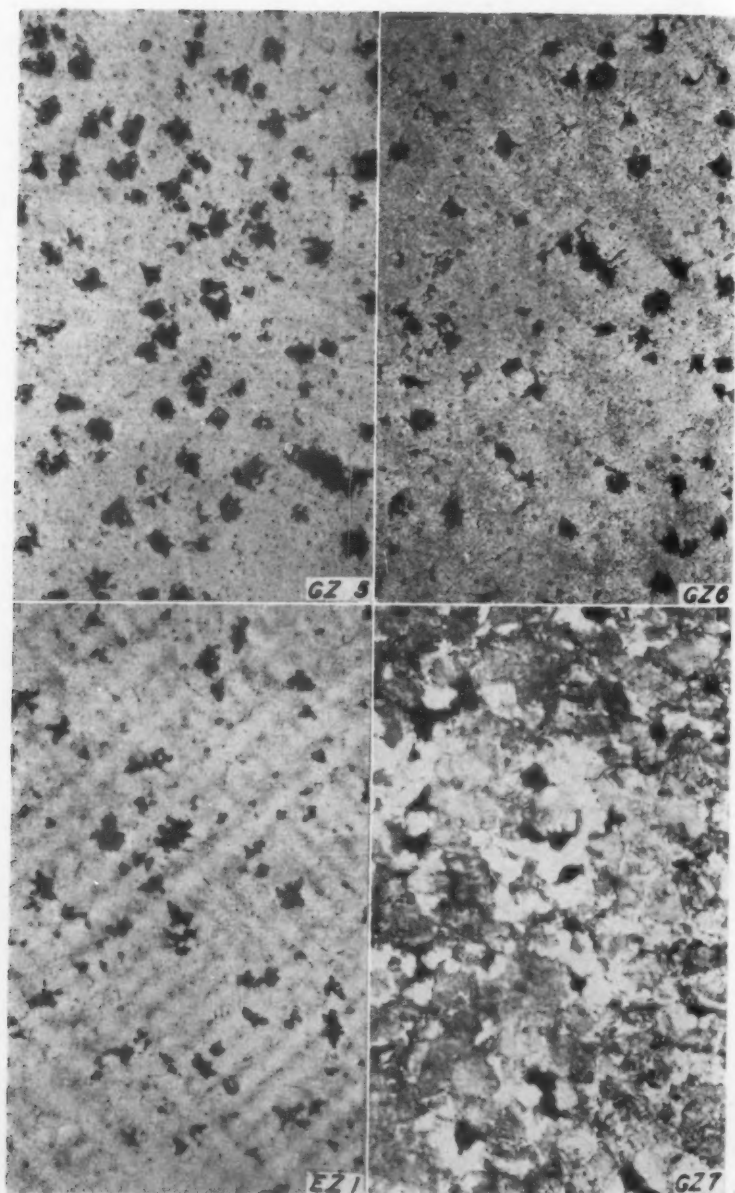


FIG. 4—PHOTOMICROGRAPHS OF MALLEABLE IRONS GZ5 TO GZ7 AND EZ1 "AS RECEIVED". MAGNIFICATION 50X.

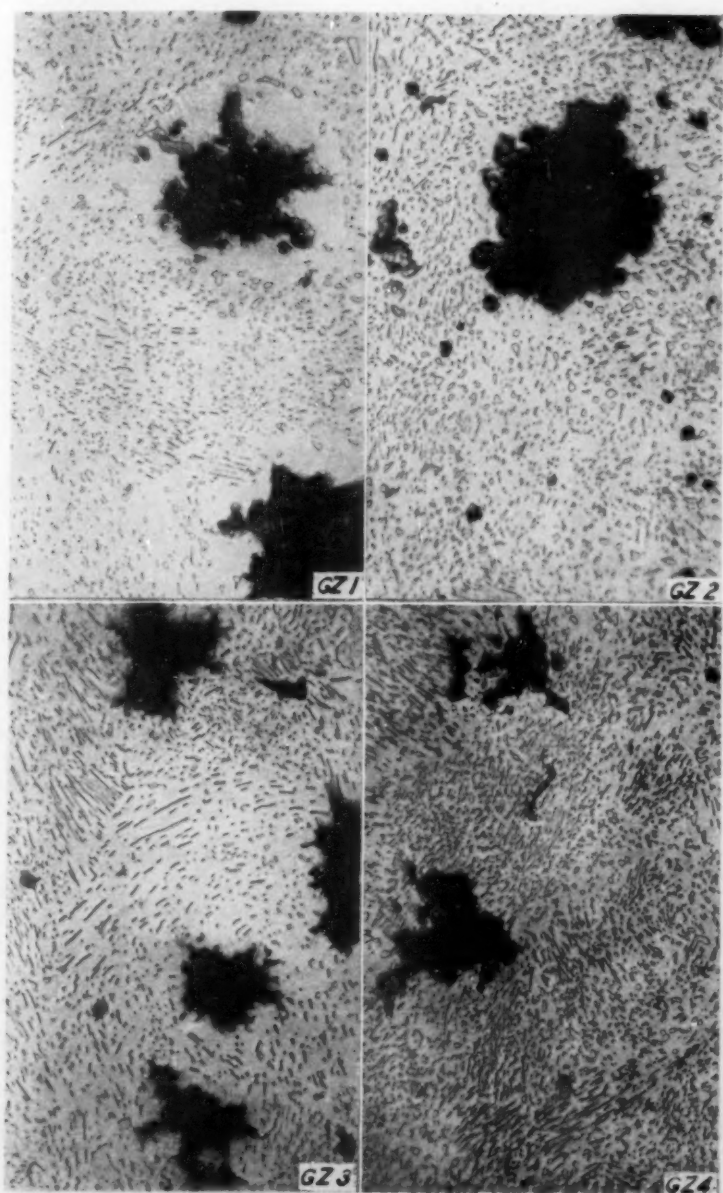


FIG. 5—PHOTOMICROGRAPHS OF MALLEABLE IRONS GZ1 TO GZ4 "AS RECEIVED". MAGNIFICATION: 500X.

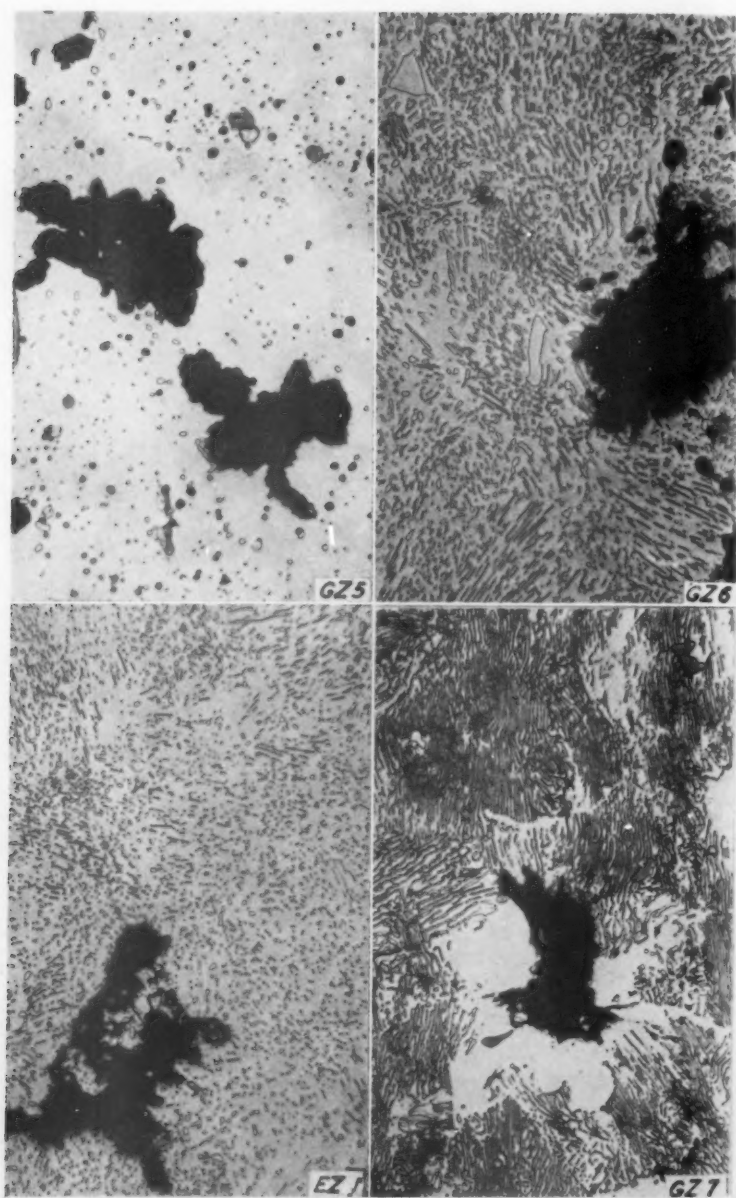


FIG. 6—PHOTOMICROGRAPHS OF MALLEABLE IRONS GZ5 TO GZ7 AND EZ1 "AS RECEIVED". MAGNIFICATION 500X.

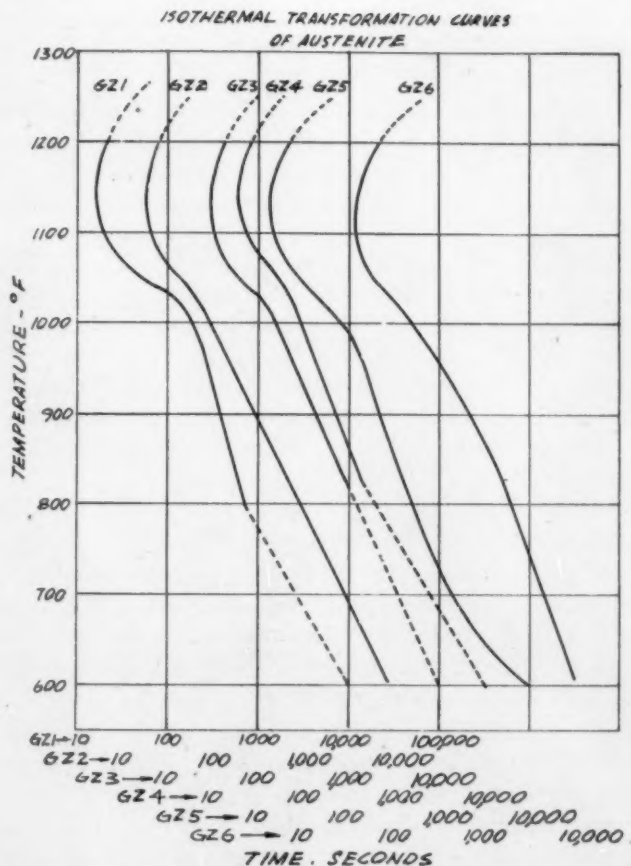


FIG. 7—CURVES FOR THE END OF ISOTHERMAL REACTION FOR MALLEABLE IRONS GZ1 TO GZ6, QUENCHED FROM 1700° F.

iron shown in Table 1 (except GZ7) when quenched from 1700° F. was determined by means of dilation studies as previously described. The curves in Fig. 7 show the time (plotted as the log. of time) required for complete transformation of the austenite in specimens GZ1 to GZ6 at temperatures between 1200 and 600° F. Specimen GZ5 which had the lowest manganese content started to transform sooner than any other specimen and the transformation was completed before any other specimen had completed its transformation at the various temperatures at which the transformation was studied. Specimen GZ6 which had the maximum manganese content of series GZ1 to GZ6 was the most sluggish in transforming. Specimen GZ6 started to transform later than any other in the series and was the last one to complete the transformation at any of the temperatures at which the transformation was caused to take place.



19. The microstructures resulting from various conditions of transformation are shown in Figs. 8 and 9 for specimens of the GZ1 grade of iron. The microstructures are described as follows:

- (1) The furnace-cooled specimen contained coarse, lamellar pearlite, and was the only one to show a network of free ferrite.
- (2) The air-cooled specimen contained lamellar pearlite which had a considerable range from a coarse to a medium inter-lamellar spacing.
- (3) The specimens cooled in lead at 1200, 1100, and 1000° F. had lamellar pearlite of uniform character for any one specimen but which decreased slightly in inter-lamellar spacing in the order named.
- (4) The specimen quenched in lead at 900° F. had a bainite structure with some outlining of the prior austenite grains with fine pearlite.
- (5) The specimen quenched in lead at 800° F. had a uniform bainite structure.
- (6) The specimen quenched in lead-bismuth to 600° F. had an acicular structure of lower bainite which was quite similar to martensite.

20. Of the microstructures discussed above and shown in Figs. 8 and 9 only five represent the prior structures for studies of the effects of spheroidization on the physical properties. The five structures are those for the following conditions: furnace and air cooled, quenched in lead at 1000° F. and 800° F., and quenched in lead-bismuth at 600° F.

21. The tensile strength and elongation of all specimens in the "as quenched" condition and after spheroidization for 10 and 36 hr. are shown in Fig. 10. A comparison is given in Fig. 11 for series *E* specimens quenched to 600° F. which were spheroidized for 5 and 10 hr.

22. The tensile tests for series *A*, *B*, *C*, *D*, and *E* are given, respectively in Tables 2 to 6, inclusive.

23. In Fig. 12, curves are given for the various grades of iron in which the Brinell hardness is plotted as ordinate and the log. of the time of spheroidization is the abscissa. The hardness value for zero time is the hardness of the "as quenched" iron and the temperature of spheroidization was uniformly the same, 1280° F. All of the hardness tests were made with the Rockwell diamond brale and a load of 60 kilograms, the Rockwell "A" readings thus obtained were converted to Brinell hardness by means of the Rockwell conversion chart.

24. A study of the microstructure of all of the specimens was made in order to follow the progress of spheroidization. A highly consistent trend was noted for all of the irons in correlation of the observed microstructure with the hardness values. The series of micrographs in Figs. 13 to 16, which are for the GZ1 iron, are typical of the entire study and show the effect of the initial carbide type, and dispersion on the rate of softening at 1280° F.



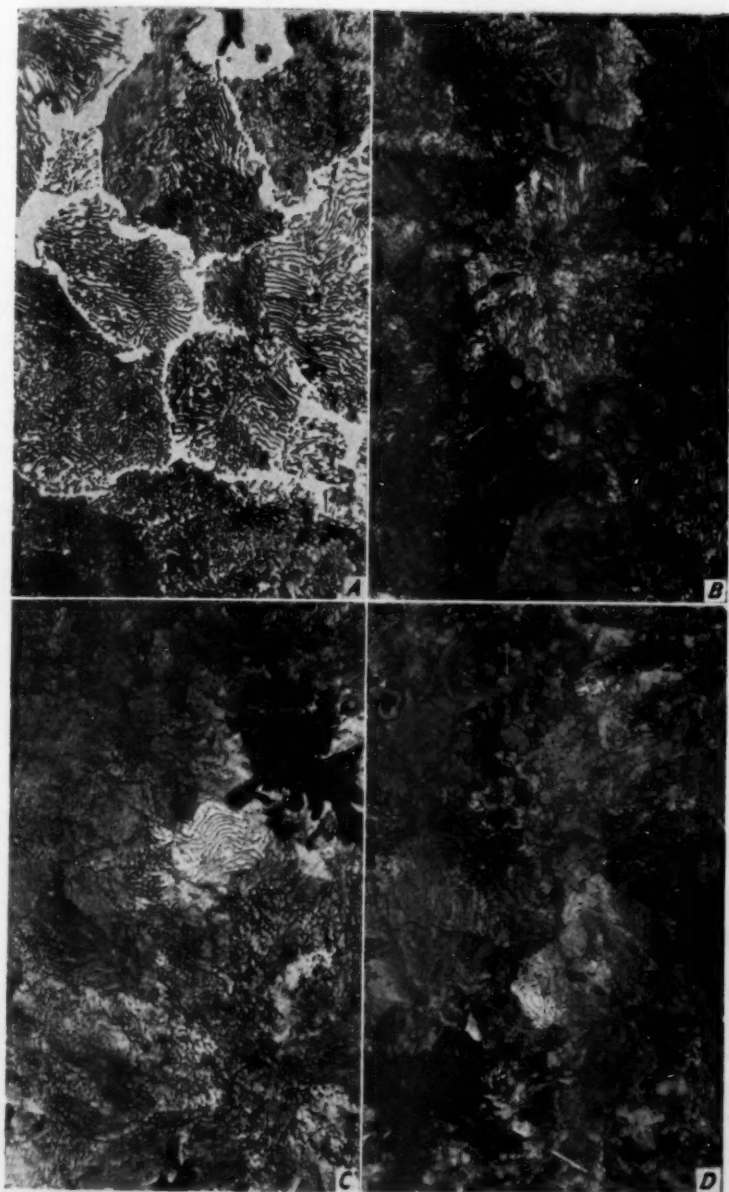


FIG. 8.—PHOTOMICROGRAPHS OF MALLEABLE IRON GZ1 QUENCHED FROM 1700° F.: A—FURNACE COOLED. B—AIR COOLED. C—LEAD QUENCHED AT 1200° F. D—LEAD QUENCHED AT 1100° F. SPECIMENS WERE HELD IN QUENCHING POT FOR 150 PER CENT OF THE TIME REQUIRED FOR COMPLETE TRANSFORMATION. MAGNIFICATION 500X.

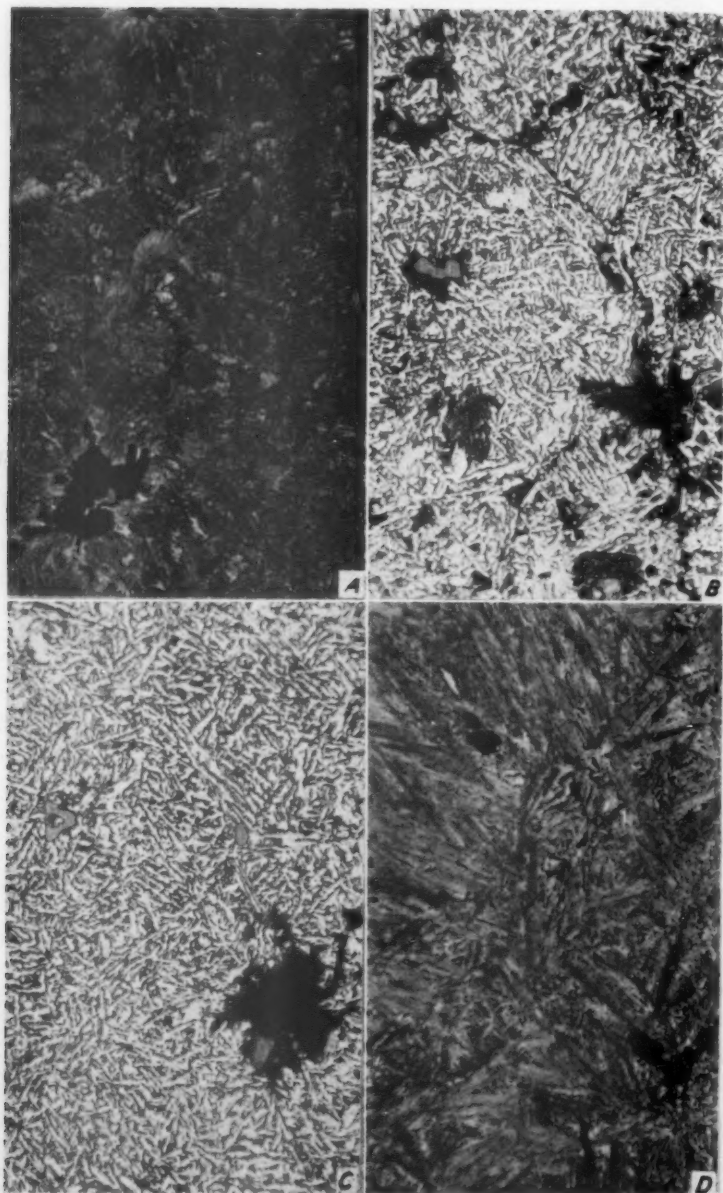


FIG. 9—PHOTOMICROGRAPHS OF MALLEABLE IRON GZ1 QUENCHED FROM 1700° F.: A—LEAD QUENCHED AT 1000° F. B—LEAD QUENCHED AT 900° F. C—LEAD QUENCHED AT 800° F. D—LEAD-BISMUTH QUENCHED AT 600° F. SPECIMENS WERE HELD IN QUENCHING POT FOR 150 PER CENT OF THE TIME REQUIRED FOR COMPLETE TRANSFORMATION. MAGNIFICATION 500X.

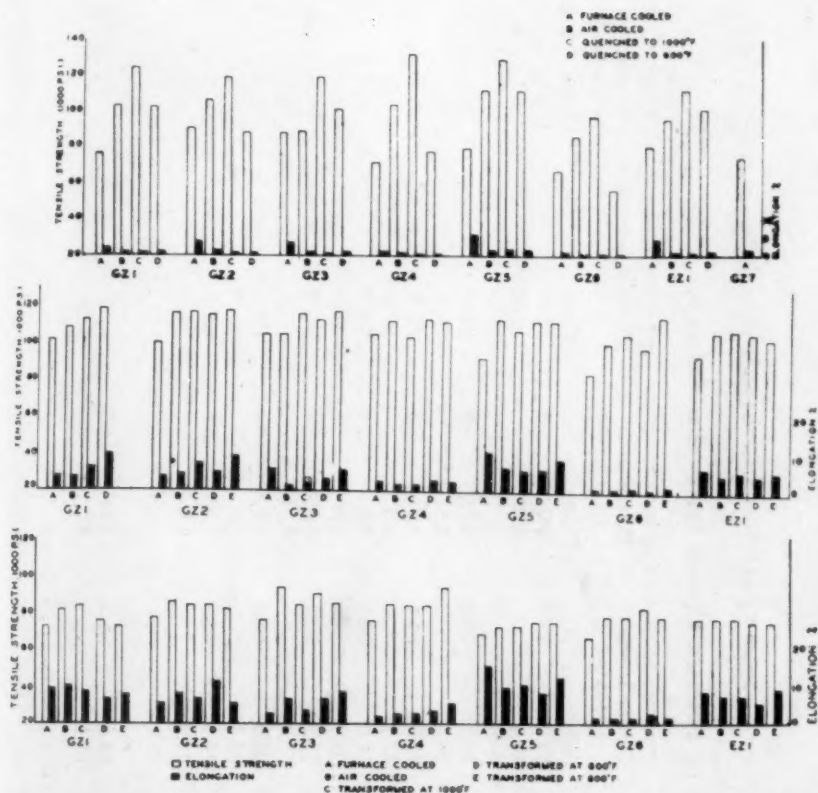


FIG. 10—SUMMARY OF DATA ON TENSILE TESTS MADE ON SPECIMENS OF SERIES A TO E BEFORE AND AFTER SPHEROIDIZATION. TOP—AS QUENCHED. MIDDLE—SPHEROIDIZED 10 HR. BOTTOM—SPHEROIDIZED 36 HR.

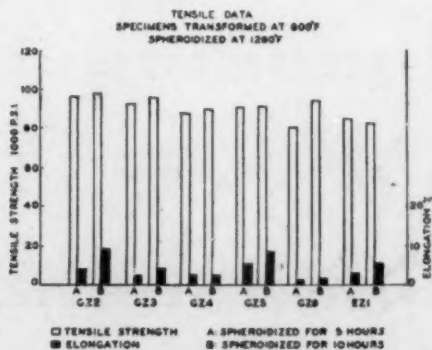


FIG. 11—SUMMARY OF DATA ON TENSILE TESTS MADE ON SPECIMENS OF SERIES E AFTER SPHEROIDIZING FOR 5 AND 10 HR.

Table 2  
TENSILE PROPERTIES OF FURNACE COOLED SPECIMENS—SERIES A

Spec. No.	Not Spheroidized			Spheroidized 10 hr.			Spheroidized 36 hr.		
	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.
	Tests	Av.	Tests	Tests	Av.	Tests	Tests	Av.	Tests
GZ1	72.2*	75.0	1.5	81.2	80.8	4.0	72.7	72.7	14.0
	69.0		1.5	80.4		4.0	71.35		4.5
	83.75		2.5						
GZ2	98.3*	90.2	5.0	81.2	79.0	4.0	74.65	77.0	4.5
	82.0		2.5	76.85		3.5	79.3		6.5
	84.8	86.9	2.5	85.3	84.3	3.5	71.5	76.1	2.5
GZ3	89.0		3.5	83.2		7.5	80.65*		3.0
	76.7	70.7	1.5	81.9	85.1	2.5	70.7*	74.5	1.5
	64.65*		0.5	88.2		3.0	78.3*		2.5
GZ4	78.8*	79.5	4.5	75.65	70.8	14.5	67.25	68.1	14.5
	80.2*		4.5	65.95		6.5	69.0		16.5
	71.0*	66.5	1.5	58.5	61.8	1.0	65.9	66.3	1.5
GZ5	62.0*		0.5	65.15		1.0	66.7*		1.0
	72.8*	80.4	2.5	74.3	74.3	7.0	67.4	71.9	9.0
	74.7*		2.5	74.35		5.5	76.3		8.0
GZ6	86.5		4.0						
	87.7		4.5						
	74.6*	74.4	1.5	68.5	68.8	4.4	62.8	62.8	7.0
EZ1	74.25		2.0	69.1		4.0	62.8		6.5

\*Denotes specimen which broke outside of gage length or showed blowholes in the fracture.

Table 3

## TENSILE PROPERTIES OF AIR COOLED SPECIMENS—SERIES B

Spec. No.	Not Spheroidized			Spheroidized 10 hr.			Spheroidized 36 hr.		
	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.
	Tests	Av.		Tests	Av.		Tests	Av.	
GZ1	107.3	102.8	1.0	82.3	87.4	2.5	79.6	81.5	10.0
	98.3		0.5	92.4		4.0	83.3		10.5
GZ2	96.65	104.9	1.0	97.8	95.2	5.0	82.7	84.5	9.0
	113.1		1.0	92.6		4.0	87.2		7.5
GZ3	98.3*	88.1	0.5	99.3	83.5	3.0	93.8	...	7.0
	77.8*		0.5	67.7*		0.5			
GZ4	97.5	102.9	0.5	92.0*	91.6	2.0	92.5	84.0	4.0
			0.5	91.2*		1.5	75.5		1.5
GZ5	109.8	112.0	1.0	92.6	93.3	7.0	69.1	70.6	9.5
	114.2		1.5	94.0		6.5	72.15		10.5
GZ6	89.45	85.8	0.5	68.2	79.3	1.5	81.2	77.1	1.5
	82.15		0.0	90.75		0.5	72.9*		1.0
EZ1	98.9	95.5	1.0	92.3	86.8	5.0	75.1	74.7	7.5
	92.0		0.5	81.3		4.0	74.2		7.0

\*Denotes specimen which broke outside of gage length or showed blowholes in the fracture.

Table 4

## TENSILE PROPERTIES OF ISOTHERMALLY TRANSFORMED SPECIMENS—1000° F. QUENCH—SERIES C

Spec. No.	Not Spheroidized			Spheroidized 10 hr.			Spheroidized 36 hr.		
	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.
	Tests	Av.	Tests	Tests	Av.	Tests	Tests	Av.	Tests
GZ1	101.8 146.5	124.2	0.5 1.5	90.4 94.2	92.4	6.0 6.5	84.3 81.9	83.1	8.5 9.5
GZ2	128.9 108.0	118.5	0.5 0.0	99.6 92.2	95.9	8.5 5.5	79.6 86.3	82.5	5.5 8.5
GZ3	114.8* 121.2	118.0	0.0 0.0	94.65 95.9	95.3	3.0 4.0	81.0 87.7*	84.4	2.5 5.5
GZ4	131.2 53.4*	131.2	0.0 0.0	73.8* 91.0	82.4	0.0 2.0	89.35 77.3	83.3	3.5 2.5
GZ5	134.2 122.9	128.6	1.5 1.5	82.5 91.6	87.1	4.5 7.0	70.8 72.0*	71.4	11.5 10.0
GZ6	84.8* 107.9	96.4	0.0 0.0	85.35 86.5	85.35	1.5 5.0	74.5 78.9	76.7	1.0 2.0
EZ1	106.9 117.1	112.0	0.5 0.5	88.6	87.6	5.3 5.5	76.3 75.9	76.1	7.0 7.5

\*Denotes specimen which broke outside of gage length or showed blowholes in the fracture.



Table 5  
TENSILE PROPERTIES OF ISOTHERMALLY TRANSFORMED SPECIMENS—800° F. QUENCH—SERIES D

Spec. No.	Not Spheroidized			Spheroidized 10 hr.			Spheroidized 36 hr.		
	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.
	Tests	Av.	Tests	Tests	Av.	Tests	Tests	Av.	Tests
GZ1	101.0 103.8	102.4	1.0 1.0	92.8 101.3	97.1	9.0 10.5	74.1 75.6	74.9	7.0 6.5
GZ2	83.0 91.3	87.2	0.5 0.0	96.5 92.35	94.4	5.0 5.0	81.8 85.2	83.5	9.0 14.0
GZ3	79.3 120.8*	100.0	0.5 1.0	93.0 91.3	92.2	3.0 3.0	91.3 87.4	89.4	8.0 6.0
GZ4	83.1 71.4*	77.3	0.5 0.0	96.9 89.2	93.1	3.0 3.0	83.2	.... (83.2)	3.5 (3.5)
GZ5	122.7 99.4	111.1	2.0 1.0	90.35* 93.5	91.9	5.0 7.0	70.5 78.3	74.4	6.5 10.5
GZ6	55.5 56.1	55.8	0.0 0.0	81.2 74.3*	77.8	1.0 0.0	79.0 84.6	81.8	2.0 3.5
EZ1	107.6 94.5	101.1	1.5 0.5	83.2 88.15	85.7	4.0 5.0	74.8 61.5	68.2	7.0 3.0

\*Denotes specimen which broke outside of gage length or showed blowholes in the fracture.

Table 6  
TENSILE PROPERTIES OF ISOTHERMALLY TRANSFORMED SPECIMENS—600° F. QUENCH—SERIES E

Spec. No.	Not Spheroidized			Spheroidized 10 hr.			Spheroidized 36 hr.		
	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.	Tensile Strength, 1000 psi.		Elongation, Per Cent in 2 in.
	Tests	Av.	Tests	Tests	Av.	Tests	Tests	Av.	Tests
GZ2	94.9	97.5	3.0	98.8	98.3	9.0	84.9	80.8	7.5
	100.0		5.5	97.8		9.0	76.65		4.0
GZ3	86.6	87.7	2.0	96.0	97.7	4.5	79.75	84.5	10.0
	88.7		3.0	99.4		3.5	89.3		8.0
GZ4	76.3	88.7	0.5	90.0	90.9	2.0	92.5	92.8	5.5
	101.1		5.0	95.4		3.5	93.0		6.5
GZ5	95.3	92.2	8.5	87.15		2.0			
	89.15*		3.0	92.8	92.3	8.5	73.3	74.4	11.0
GZ6	83.85	81.6	1.5	91.7		9.0	75.4		14.0
	79.4		1.5	102.5*	94.7	1.5	79.3	76.9	2.0
EZ1	86.0	...	3.5	86.8		2.0	74.4*		1.5
				80.8	82.9	4.0	73.5	74.0	10.0
GZ7	83.0	86.60	2.0	84.9		6.5	74.5		9.0
	90.2*		3.0	82.2	76.4	3.5	73.15	71.5	8.0
				70.5*		0.5	69.8		8.0

\*Denotes specimen which broke outside of gage length or showed blowholes in the fracture.

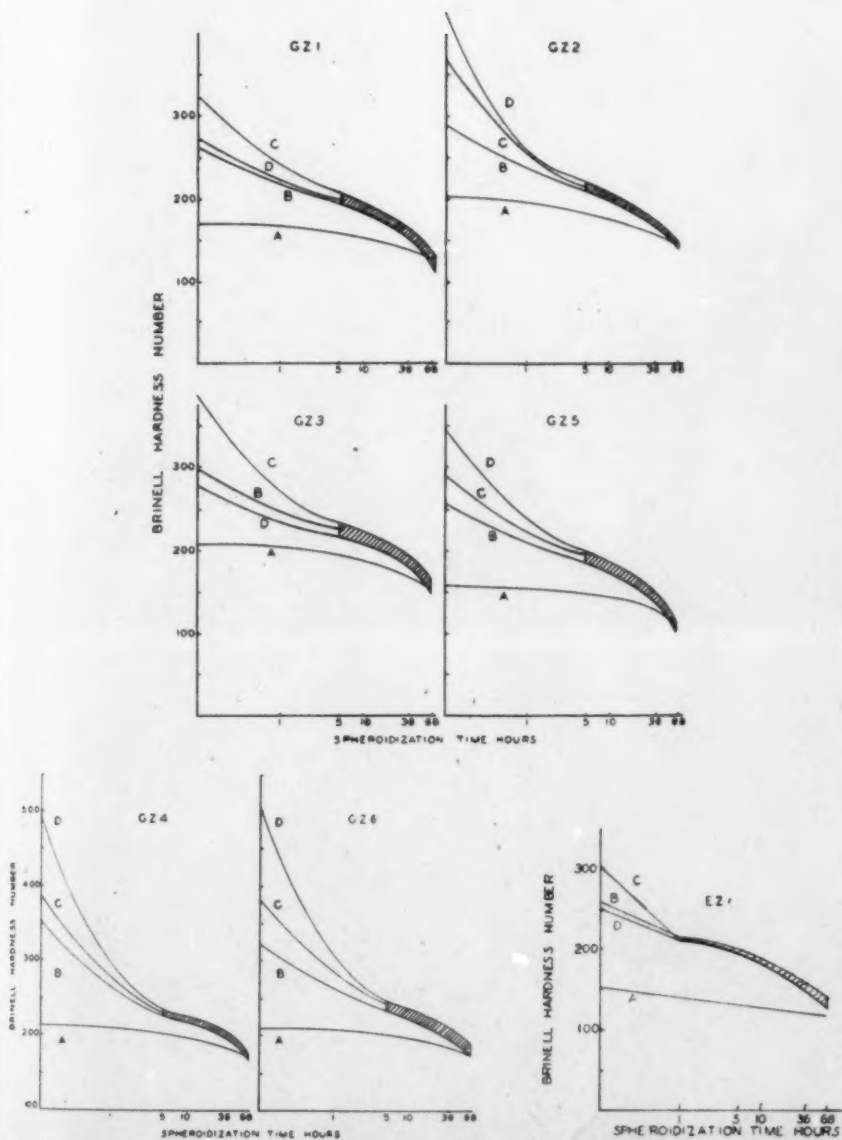


FIG. 12—CURVES OF BRINELL HARDNESS VERSUS LOGARITHM OF TIME OF SPHEROIDIZATION. A—FURNACE COOLED, B—AIR COOLED, C—TRANSFORMED AT 1000° F, D—TRANSFORMED AT 800° F. THE HARDNESS VALUE FOR ZERO TIME IS THE HARDNESS OF THE "AS QUENCHED" IRON. THE TEMPERATURE OF SPHEROIDIZATION WAS 1280° F.

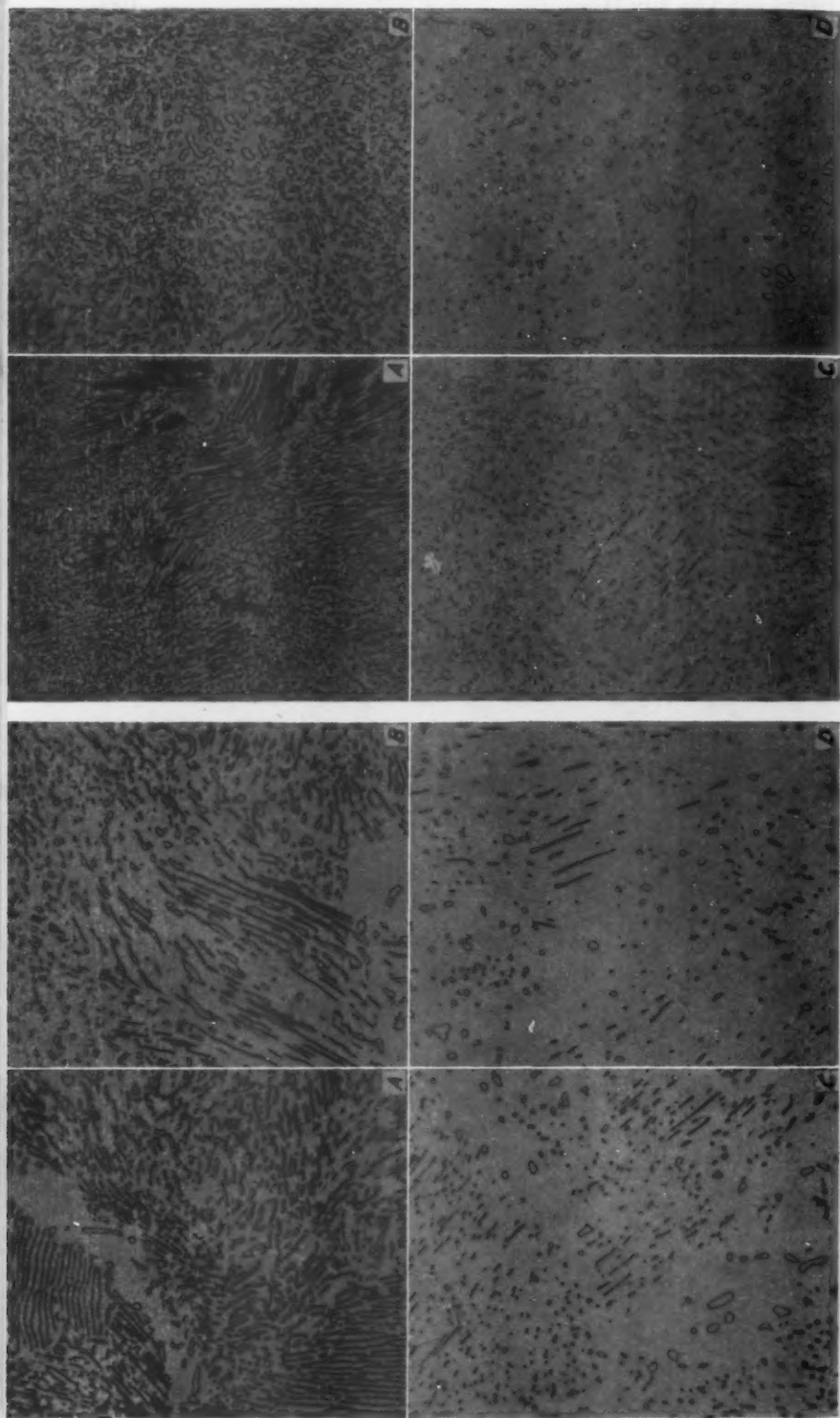


FIG. 13.—LEFT—PHOTOMICROGRAPHS OF SPECIMENS OF C21 MALLEABLE IRON SERIES A, FURNACE COOLED, SHOWING PROGRESS OF SPHEROIDIZATION AT 1280° F. A—After 10 hr. B—After 36 hr. C—After 10 hr. D—After 36 hr. RIGHT—PHOTOMICROGRAPHS OF SPECIMENS OF C21 MALLEABLE IRON SERIES B, AIR COOLED, SHOWING PROGRESS OF SPHEROIDIZATION AT 1000° F. A—After 10 hr. B—After 36 hr. C—After 10 hr. D—After 36 hr. MAGNIFICATION 1000X.

FIG. 13—LEFT—PHOTOMICROGRAPHS OF SPECIMENS OF GZ1 MALLEABLE IRON SERIES A, FURNACE COOLED, SHOWING PROGRESS OF SPHEROIDIZATION AT 1280° F. A—After 3 hr., B—After 10 hr., C—After 36 hr., D—After 68 hr. Right—Photomicrographs of specimens of GZ1 MALLEABLE IRON SERIES B, AIR COOLED, SHOWING PROGRESS OF SPHEROIDIZATION AT 1000° F. A—After 3 hr., B—After 10 hr., C—After 36 hr., D—After 68 hr.

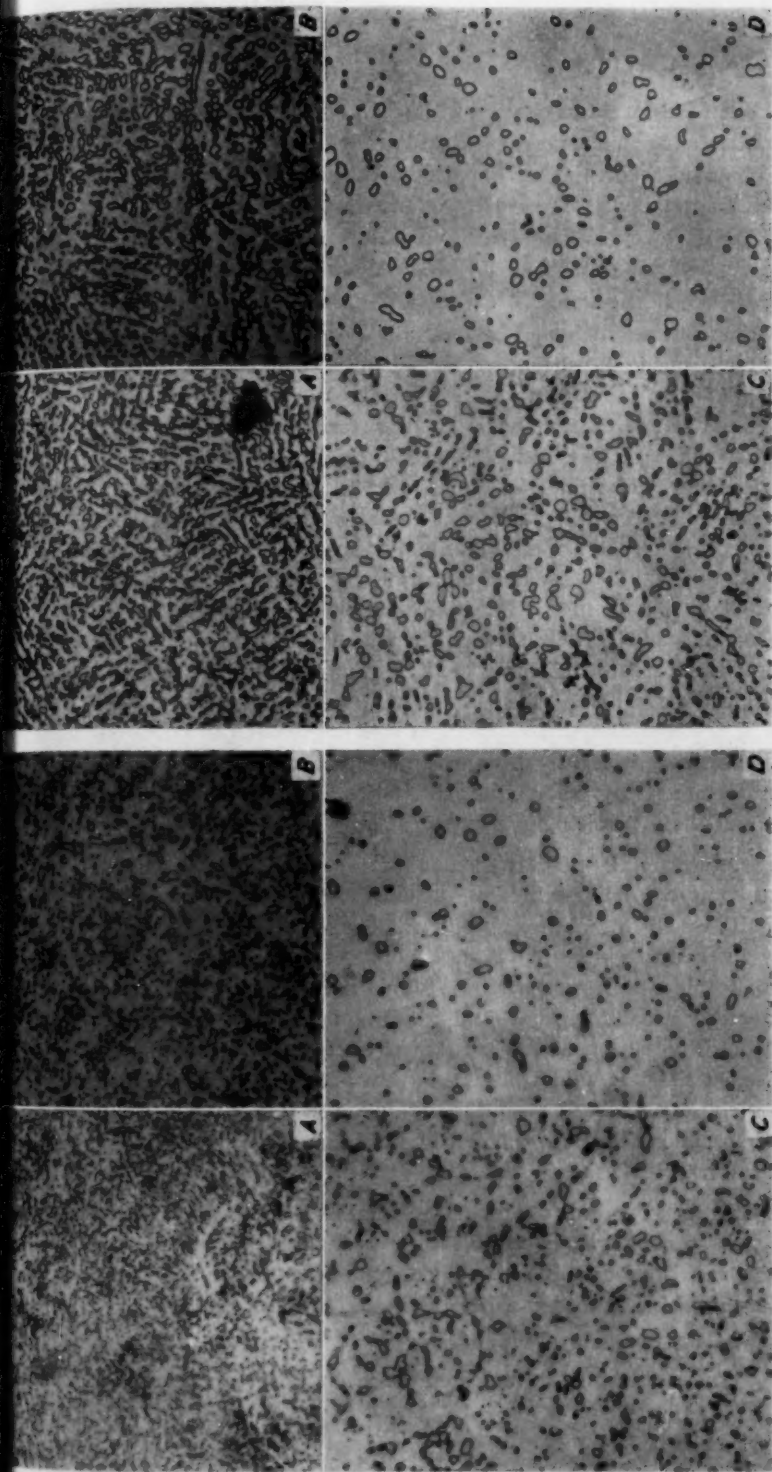


FIG. 15—LEFT—PHOTOMICROGRAPHS OF SPECIMENS OF GZ1 MALLEABLE IRON SERIES C, ISOTHERMALLY QUENCHED AT 1000° F., SHOWING PROGRESS OF SPHEROIDIZATION AT 1280° F. A—After 3 hr., B—After 10 hr., C—After 36 hr., D—After 68 hr. Right—Photomicrographs of specimens of GZ1 MALLEABLE IRON SERIES D, ISOTHERMALLY QUENCHED AT 800° F., SHOWING PROGRESS OF SPHEROIDIZATION AT 1280° F. A—After 3 hr., B—After 10 hr., C—After 36 hr., D—After 68 hr. Magnification 1000X.

## DISCUSSION OF THE DATA

25. The hardness data as plotted in Fig. 12 against the log. of the time at the spheroidization temperature of 1280° F. are the most consistent of any of the data obtained. The higher the initial hardness of the irons the more rapidly the hardness decreased with spheroidization time. However, after 5 hr. at 1280° F. all of the irons showed little difference in hardness for the series *B*, *C*, and *D* specimens while a considerable difference still remained after 5 hr. between the series *B*, *C*, and *D* specimens as a group compared with the series *A* specimens. The series *A* specimens were furnace cooled, and had the coarsest initial structure, consequently they were the most reluctant to spheroidize. The micrographs in Figs. 13 to 16 indicate that after 68 hr. at 1280° F. the series *A* specimen was still not entirely spheroidized, thus in Fig. 12 the hardness of the series *B*, *C*, and *D* specimens for most of the irons was slightly below the hardness of the *A* series specimens at the end of 68 hr. In the unspheroidized condition, series *C* specimens of the GZ1, GZ3, and EZ1, iron quenched to 1000° F. and isothermally transformed, had the maximum hardness. Of the GZ2, GZ4, and GZ6 irons, the series *D* specimens transformed at 800° F. had a higher hardness than those of the *C* series. For the specimens of GZ3 and EZ1 irons, the *D* series had a lower hardness than the specimens of the air cooled *B* series. The tensile strength in the unspheroidized condition did not correspond with the hardness values; all of the series *C* specimens in the unspheroidized condition had the maximum tensile strength. The unspheroidized series *A* specimens had the minimum tensile strength except for specimens of grade GZ2 and GZ6 iron for which the series *D* specimens had the lowest strength.

26. It is unfortunate that, in general, for each test condition only two tensile tests could be made on the "as quenched" irons, and the irons spheroidized for 5, 10, or 36 hr. With entirely sound specimens having fair ductility, reasonably good checks in the tensile tests could have been expected but in the pearlitic malleable type iron specimens studied there was general unsoundness, and fair ductility usually was not established until after 36 hr. of spheroidization. It would have been desirable to make an average of five to ten tensile tests and reject the test values obtained from obviously defective specimens; however, such a procedure would have involved not only a tremendous number of specimens but also an inordinate amount of time for heat treatment and testing.

27. In assessing the indications of the tensile test data, usually based on the average of two tests, it is possible to note the general trend of the data and review the existing exceptions to these trends. From the charts of Fig. 10 and the data in Tables 2 to 6, inclusive, it is established that:

*In the "As Quenched" Condition:*

- (1) The tensile strength increased consistently for each grade of iron in



the order of series *A*, *B*, *C*, while the ductility decreased in the reverse order.

- (2) The series *D* specimens were consistently lower in tensile strength than the series *C* specimens but did not have a constant relationship with the series *A* or series *B* specimens.

*After 10 Hr. of Spheroidization at 1280° F.:*

- (1) The tensile strength was, in general, lower than that of the unspheroidized specimens. The exceptions are specimens GZ1 and GZ4 of the *A* series and specimens GZ2, GZ4, and GZ6 of the *D* series, all of which had a higher strength than the corresponding, unspheroidized specimens.
- (2) The ductility of the specimens increased as compared with the unspheroidized specimens. The exceptions are the GZ2 and GZ6 specimens of the *A* series which had the same elongation as the unspheroidized specimens.

*After 36 Hr. of Spheroidization at 1280° F.:*

- (1) The tensile strength was, in general, lower than that of the specimens spheroidized for 10 hr. The exceptions are specimen GZ6 of the *A* series, specimen GZ3 of the *B* series, specimen GZ4 of the *C* series, and specimen GZ6 of the *D* series.
- (2) The ductility of the specimens increased as compared with the specimens spheroidized for 10 hr. The exceptions are specimens GZ3 and GZ4 of the *A* series, and specimens GZ1 and GZ4 of the *D* series. All of the exceptions had greater ductility after 10 hr. of spheroidization than after 36 hr. of spheroidization but the ductility after 36 hr. of spheroidization was greater than that for the unspheroidized specimens with the exception only of specimen GZ3 of the *A* series.

28. In the unspheroidized condition, the generally higher ductility of the furnace-cooled specimens, series *A* was especially noteworthy. However, in single-specimen, tensile tests made on only specimens GZ5 and EZ1 in the "as received" condition values were obtained as follows:

	<i>Tensile Strength</i>	<i>Elongation</i>
Spec. GZ5	67,700 psi.	11.5 per cent
Spec. EZ1	79,900 psi.	10.0 per cent

Comparison of these values with the data on the similar specimens in Fig. 10 and in Tables 2 to 6 is particularly disappointing since the above ductility of the single GZ5 specimen was exceeded on the average only in series *A* and *E* after 36 hr. of spheroidization, while specimen EZ1 never reached 10 per cent average elongation in any condition of heat treatment. There was, however, for the two grades of iron, a close approach to the above cited ductility with a considerably higher tensile strength in many conditions of the heat treatment reported.

29. The most promising data are those for the 10 hr. spheroidization since

a considerable improvement in ductility was obtained, compared with the unspheroidized specimens, and the tensile strength was not as seriously impaired as by the 36-hr. spheroidization. The specimens of the GZ5 grade of iron appeared to have outstanding properties, especially after 10 hr. of spheroidization. There was a marked improvement in ductility of the GZ5 iron in particular after 36 hr. spheroidization but the tensile strength was reduced to a minimum for the entire series of irons.

30. The maximum tensile strength recorded was for the single specimen of the GZ1 iron in the unspheroidized condition, Table 4, which had been isothermally transformed at 1000° F. The high strength of 146,500 psi. was accompanied by a relatively high elongation of 1.5 per cent as compared with other specimens of this series in the unspheroidized condition.

31. The maximum ductility recorded was for the single specimen of the GZ5 iron in series A, furnace cooled and spheroidized for 36 hr. Table 2 shows that the specimen elongated 16.5 per cent and had a higher tensile strength than the companion specimen which elongated 14.5 per cent.

#### SUMMARY

32. The heat treatment of pearlitic malleable iron by spheroidization at 1280° F. after the first stage anneal may be controlled by the simple expedient of regulating the time of spheroidization. For practically any of the methods of cooling from the temperature of the first stage anneal, except furnace cooling, a spheroidization period of 10 hr. produced a combination of high tensile strength, and generally fair ductility. A substantial increase in ductility was obtained with a consequent large reduction of tensile strength by increasing the spheroidizing time to 36 hr.

33. The spheroidization of all series of specimens was substantially complete after 5 hr. at 1280° F. except for the furnace-cooled series; however, good ductility was not established until the number of carbide spheroids was greatly reduced by coalescence during a period of spheroidization greater than 10 hr. This behavior suggests the desirability of a quenching procedure which would produce a coarse spheroidite directly after the first stage anneal.

34. The microstructure of the GZ5 grade of iron in the "as received" condition and the physical properties of the single specimen tested in this condition suggest the possibility of adjusting the manganese content of the pearlitic malleable type of iron studied, in order to obtain complete spheroidization on slow cooling from the first stage anneal. The second stage of heating to 1280° F. for spheroidization would thus be unnecessary.

35. In the unspheroidized condition, the two treatments represented by series A, furnace cooling, and series C, isothermal quench at 1000° F., gave the specimen so treated notable properties. The series A specimens had fair elongation values but low tensile strength while the series C specimens had excellent tensile strength with negligible elongation.

## DISCUSSION

*Presiding:* A. M. FULTON, Northern Malleable Iron Co., St. Paul, Minn.

*Co-Chairman:* FRED L. WOLF, Ross Tacony Crucible Co., Tacony, Philadelphia, Pa.

J. H. LANSING, Malleable Founders' Society, Cleveland, Ohio, presented the paper in the absence of the authors.

D. P. FORBES<sup>1</sup>: Our company owes the authors some apology, due to the fact that these specimens which we submitted for use in the engineering work at the University of Illinois were not particularly good specimens; many of the bars had defects and the analyses that were set were not met very closely. The only excuse that we can offer for that is the fact that they were made under very difficult conditions. We were not producing metal commercially to the analysis desired and we attempted, by mixing liquid steel and liquid white iron, to obtain these particular carbon analyses. I do not know, and the tests do not seem to show, whether or not a metal mixed in that way would give heat-treating properties and tensile properties comparable to one which was prepared as a single melt.

One of the interesting things that have been brought out by Professor Bruckner's work is the fact that the metal in sizes, at least test bar sizes, can be isothermally quenched and apparently will give a uniform structure throughout. That probably is due to the percentages of silicon and manganese which are present in the metal, and which give it a certain deep-hardening property which an ordinary carbon steel would not have. It was hoped that the spheroidizing time could be very materially reduced by this isothermal quench, but the data in the paper do not seem to prove that point. The tensile properties do not equal the properties normally obtained commercially by material which is simply air cooled and then spheroidized.

I believe that a great deal is still to be learned about the mechanism of spheroidization. It does offer possibilities for obtaining higher ductility in pearlitic irons than normally can be obtained with a purely pearlitic matrix. Possibly the procedure that Professor Bruckner suggests of extremely slow cooling to develop spheroidite directly from austenite may yield some promising results.

D. TAMOR<sup>2</sup>: Mr. Forbes, on the matter of size; when we try to austemper an 0.85 per cent carbon steel, we can take a  $\frac{1}{8}$ -in. round after it is austempered and bend it double. Do you find that, as the size increases, the ductility changes?

MR. FORBES: I would say that most of these materials, after austempering, do not have any great amount of ductility. They have some, as the paper brings out. I believe that the GZ-5 series showed the best properties in that respect. However, the ductility is of a rather low order in that material until it has been spheroidized.

MR. TAMOR: It is possible to get a complete bainite structure in a  $\frac{1}{8}$ -in. round. Now, when we austemper, the amount of bainite we are going to get at a certain temperature depends upon the mass.

MR. FORBES: We have done none of the work ourselves and have only seen the results of it as Professor Bruckner reported, but apparently he has been able to get a completely bainite structure in the  $\frac{3}{4}$ -in. diameter of the standard malleable test bar. Now, how far we can go beyond that if we were to austemper a casting of considerable mass, I do not know.

PROF. BRUCKNER (*authors' closure*): As Mr. Forbes states, it was unfortunate that so many of the tensile bars tested had defects. However, there were a sufficient number of sound specimens to survey the trend of the effect of both heat treatment and com-

<sup>1</sup> Gunité Foundries Corp., Rockford, Ill.

<sup>2</sup> American Chain & Cable Co., York, Pa.

position on the physical properties. For two additional series of irons which we received, it was possible to examine the extent of internal flaws in each bar by means of radiographs made with the betatron. The radiographs were made by Professor D. W. Kern and his associates in the Physics Department of the University of Illinois, and the number of defects shown caused our decision to discard the material. It is our understanding that porosity in malleable iron tensile bars of the type tested can now be controlled to a high degree.

The spheroidizing time is shown by our data to be very materially reduced by the isothermal transformation, especially for the transformation temperatures in the region of 1000° F. and 600° F., but, as we have pointed out, sufficient ductility is not established immediately upon spheroidization. Good ductility is not established until a large amount of free ferrite is formed by the coalescence of the spheroidized carbides. Therefore, it appears to be of no commercial advantage to reduce the initial spheroidizing time, since the time at 1280° F. for the formation of free ferrite by coalescence of a large number of small, spheroidal carbides is approximately the same as the time necessary to obtain the required free ferrite by spheroidization of a coarse, lamellar pearlite. Because of this fact, it was suggested in the paper that direct spheroidization, if it could be accomplished by isothermally quenching at a high temperature and for a short time to produce a coarse spheroidite, would be a decided commercial advantage.

With respect to the size of a bar of malleable iron which can be isothermally quenched, we can say that 1½-in. round bars have been quenched at temperatures below 800° F. and gave fairly uniform microstructure over the cross section.

We are greatly obliged to J. H. Lansing, of the Malleable Founders' Society, for presenting our paper at the 48th Annual Meeting while the authors were unavoidably absent. We thank Messrs. Lansing, Forbes and Tamor for the attention they gave this paper.

## Studies On Bore Cracks in Flanged Fittings†

By JOSEPH A. DUMA\* AND STANLEY W. BRINSON\*, PORTSMOUTH, VA.

### Abstract

*The paper records a systematic study of the effect of various molding, thermal, and design factors on the formation of the widely publicized bore cracks in flanged castings. Not all flanges are vulnerable to bore cracking. It is stated that there is a definite minimum thickness of flange and a definite minimum thickness of wall, both in proper relation to each other, above which bore cracks rarely occur. Unfortunately, these thicknesses and ratios lie outside of the industrially usable range. The influences which tend both to suppress and to accentuate bore cracking are listed. Several methods of dealing with these cracks are discussed. The probable mechanism of bore-crack formation is also described.*

### INTRODUCTION

1. The issuance of directives by the Navy Department, early in 1943, making mandatory the inspection of bores in all main steam line flanged fittings and valves by means of magnetic particle inspection apparatus, resulted in revealing to foundrymen the presence of one more vulnerable location in their castings; a location containing defects which hitherto had been utterly escaping the three-dimensional scannings of radiographic inspection. Most perturbing of all were the high percentage of castings found containing this defect and the universality of its occurrence. True, not all foundrymen registered surprise when the seriousness of the defect was announced by the Navy. In fact, those who had been founding for years were not only aware of it, but were circumventing it by the use of external chills molded into the core, in a manner analogous to that outlined by the Navy Department in Bureau Ships Sketch 2527 of January 15, 1944, which is representative of the best current practice.

2. The defects to which reference is made are circumferential bore cracks in way of flanges. In these introductory paragraphs, the term "bore cracks" is used advisedly, in the dictionary sense, meaning: a chink or fissure; a partial separation of the parts of a substance. Later, a more restricted, technical definition will be given.

3. Because of the comparatively shallow depth ( $\frac{1}{4}$  to  $\frac{3}{8}$  in.) of bore cracks, as well as their tightness, location and perpendicularity, radiographic techniques have failed to detect them. One interrogatively wonders: For how many years, unnoticed by the field inspection agencies, have these defects been

†Published by permission of the Navy Department.

\*Metallurgist and Master Molder, respectively, Norfolk Navy Yard.

NOTE: This paper was presented at a Properties of Steel Castings Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 27, 1944.



"stowaway" incognito" into service? And, finally, what potential harm is resident in them?

4. The prolific and widespread occurrence of bore cracks under a multiplicity of varying founding conditions led the authors to believe that their formation could scarcely be attributed to any single item of foundry practice, or foundry equipment, material, or melting procedure, but rather must necessarily indicate an inherent vulnerability in section design. To verify this belief, some 80 experimental spool-type castings were made, each designed to test a single variable at a time. The most important of the variables studied in making these castings are described in the sketches and photographs in the body of the paper.

#### METHOD OF TESTING

##### Test Specimen

5. Preliminary study of several designs of flanged castings found a "spool" type of specimen of the form and size shown in Fig. 1, Plate 1, as being most susceptible to bore cracking, engendering bore cracks consistently and regularly in every instance of duplicate testing. The most critically related dimensions in the design are the flange-wall thicknesses. This specimen was, therefore, adopted as a standard for most of the tests.

##### Molding

6. All specimens were molded by the same molder in green sand molds, using a green sand facing and—except where otherwise noted—cores of the following mixtures:

##### (a) Green Sand Facing Mixture

Cape Henry Beach Sand No. 40-50	500 lb.
Bentonite*	30 lb.
Cereal Binder*	8½ lb. (5 qt.)
Water (3.2 to 4 per cent moisture)	30 lb.

##### Physical Properties

	Green	Dry
Permeability	400	600 to 750
Compression Strength, psi.	7	42 to 57
Shear Strength, psi.	3	19 to 24
Tensile Strength, psi.	..	4 to 24

##### (b) Core Sand Mixture

Jersey Silica Sand No. 60	112 qt. (360 lb.)
Cereal Binder	1 qt.
Linseed Oil	2 qt.
Water (6.5 to 7.0 per cent moisture)	26 qt.

##### Physical Properties (3½ hr., 475° F.)

	Green	Dry
Permeability	70.90	130-210
Compression Strength, psi.	....**	...***
Shear Strength, psi.	....**	154-187
Tensile Strength, psi.	2.9-3.6	97-107
Hardness		76-86

\*Trade names of products used may be obtained from the authors.

\*\*Too weak, below capacity of machine.

\*\*\*Too strong, above capacity of machine.



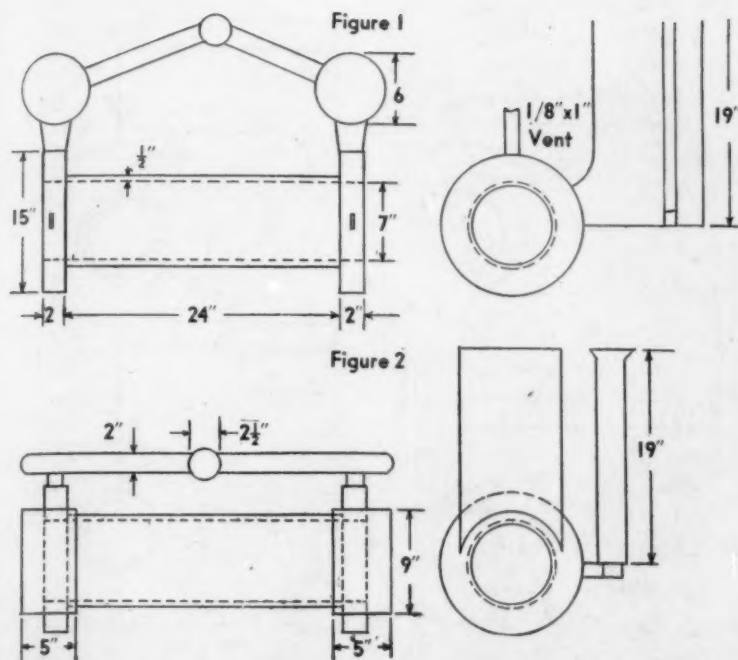
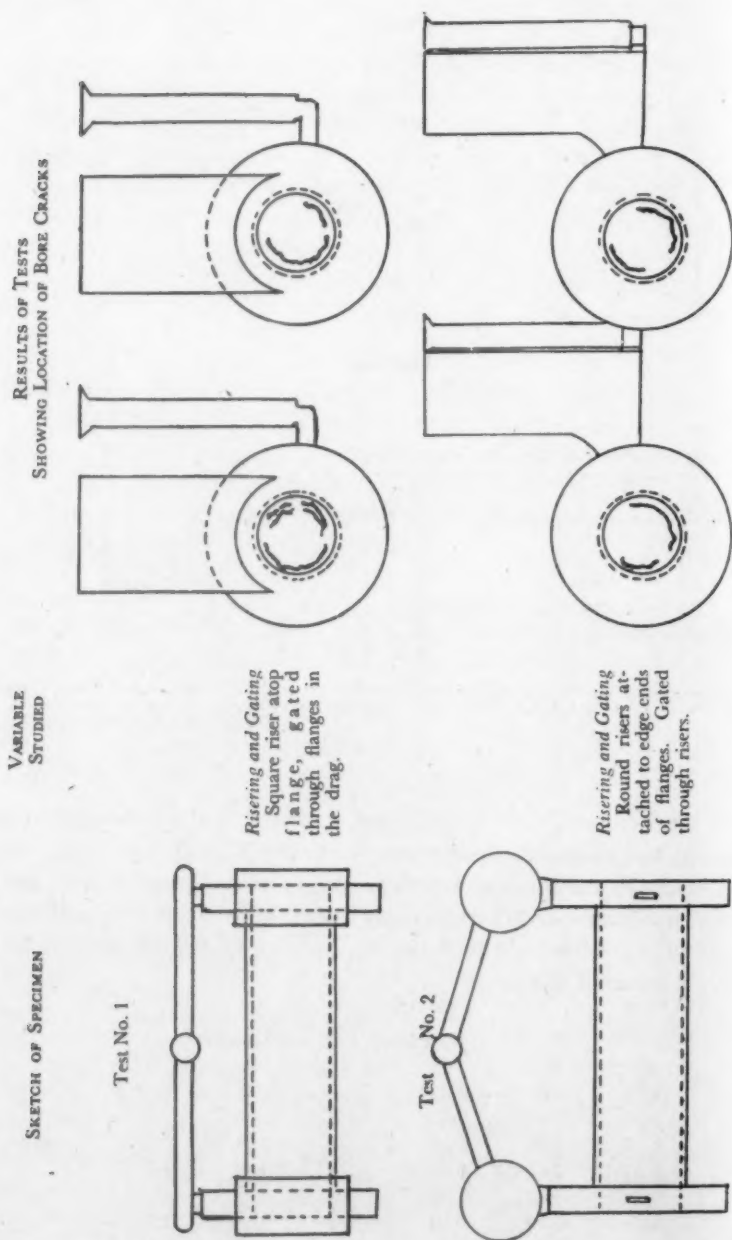


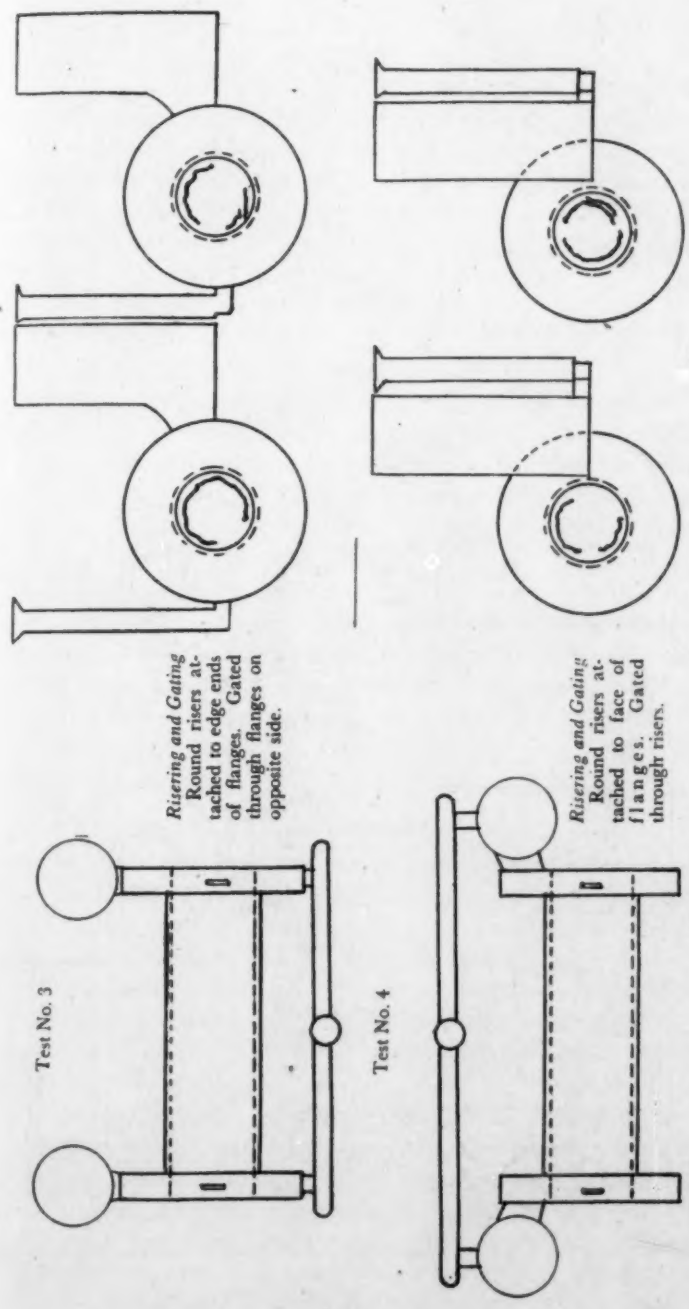
PLATE 1—DIMENSIONS, GATING AND RISERING OF TEST SPECIMENS. FIG. 1—STANDARD "SPOOL" TEST SPECIMEN. FIG. 2—COMPARATIVE TEST SPECIMEN. THIS SPECIMEN WAS DISCARDED IN FAVOR OF FIG. 1.

### Steel

7. A plain carbon, basic electric steel was used in the tests, conforming to the physical and chemical requirements for Grade B, N.D. Spec. 49S1. Several castings of 20-10 austenitic nickel-chromium corrosion resisting steel and of a low alloy manganese-nickel-copper steel also were made. Specifically, the chemistry of the steels used to make the castings illustrated in Plates 2 to 8, inclusive, is reported as follows:

Test Number	Chemical Composition, per cent							
	C	Mn	P	S	Si	Ni	Cr	Cu
1-4	0.27	0.61	0.02	0.02	0.33	0.25		0.16
1-2	0.11	0.67	0.02	0.01	0.89	10.12	20.46	
1-2	0.24	0.94	0.02	0.02	0.44	1.04	0.05	0.52
5-8	0.27	0.64	0.02	0.02	0.34	0.14		0.13
9-12	0.24	0.62	0.02	0.01	0.41	0.13		0.15
13-16	0.24	0.54	0.02	0.02	0.29	0.10		0.17
17-20	0.25	0.60	0.02	0.02	0.37	0.14		0.16
20-24	0.23	0.61	0.02	0.03	0.26	0.17		0.15
25-28	0.22	0.51	0.02	0.02	0.36	0.14		0.12
29-32	0.26	0.64	0.02	0.02	0.32	0.08		0.11





*Risling and Gating*  
Round risers at-  
tached to edge ends  
of flanges. Gated  
through flanges on  
opposite side.

*Risling and Gating*  
Round risers at-  
tached to face of  
flanges. Gated  
through risers.

PLATE 2—INFLUENCE OF GATING AND RISLING ON BORE CRACKING.

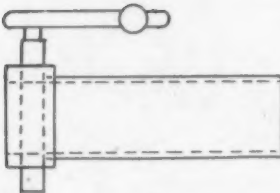
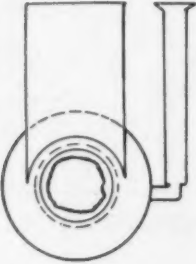
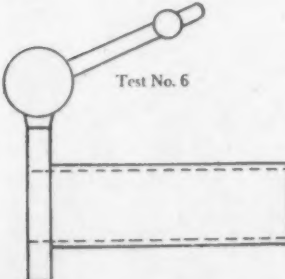
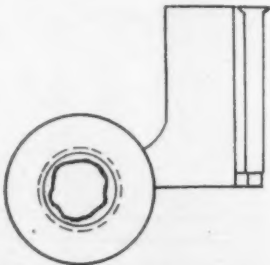
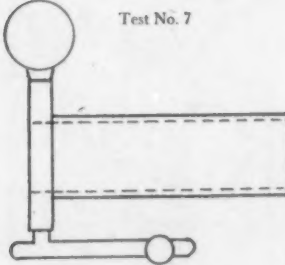
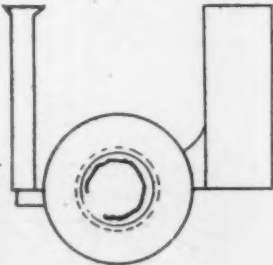
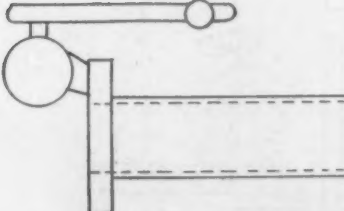
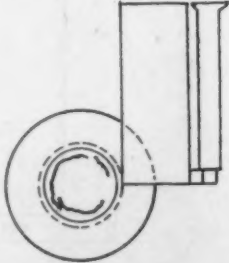
SKETCH OF SPECIMEN	VARIABLE STUDIED	RESULTS OF TESTS SHOWING LOCATION OF BORE CRACKS
<p>Test No. 5</p> 	<p><i>Risering and Gating Same as Test No. 1, except single flange.</i></p>	
<p>Test No. 6</p> 	<p><i>Risering and Gating Same as Test No. 2, except single flange.</i></p>	
<p>Test No. 7</p> 	<p><i>Risering and Gating Same as Test No. 3, except single flange.</i></p>	
<p>Test No. 8</p> 	<p><i>Risering and Gating Same as Test No. 4, except single flange.</i></p>	

PLATE 3—INFLUENCE OF GATING AND RISERING OF SINGLE-FLANGED FITTINGS ON BORE CRACKING.

### *Inspection for Cracks*

8. Each spool casting was sand blasted, ground smooth in the bore in way of the flanges, and magnetic powder tested for cracks. The periphery of all bores was prod-contacted at four points, 90 degrees apart, and magnetized with 1000 amperes rectified alternating current supplied from a rectifier unit. Pearl gray powder was dusted on while the current remained on. In addition, several flanges were burned off and sectioned for metallographic examination of cracks. The corrosion resisting steel spools were ground clean and kerosene-whiting tested for cracks, using a dyed penetrant and an aerosol-water solution of powdered chalk.

## DISCUSSION OF RESULTS

### *Gating and Riser*

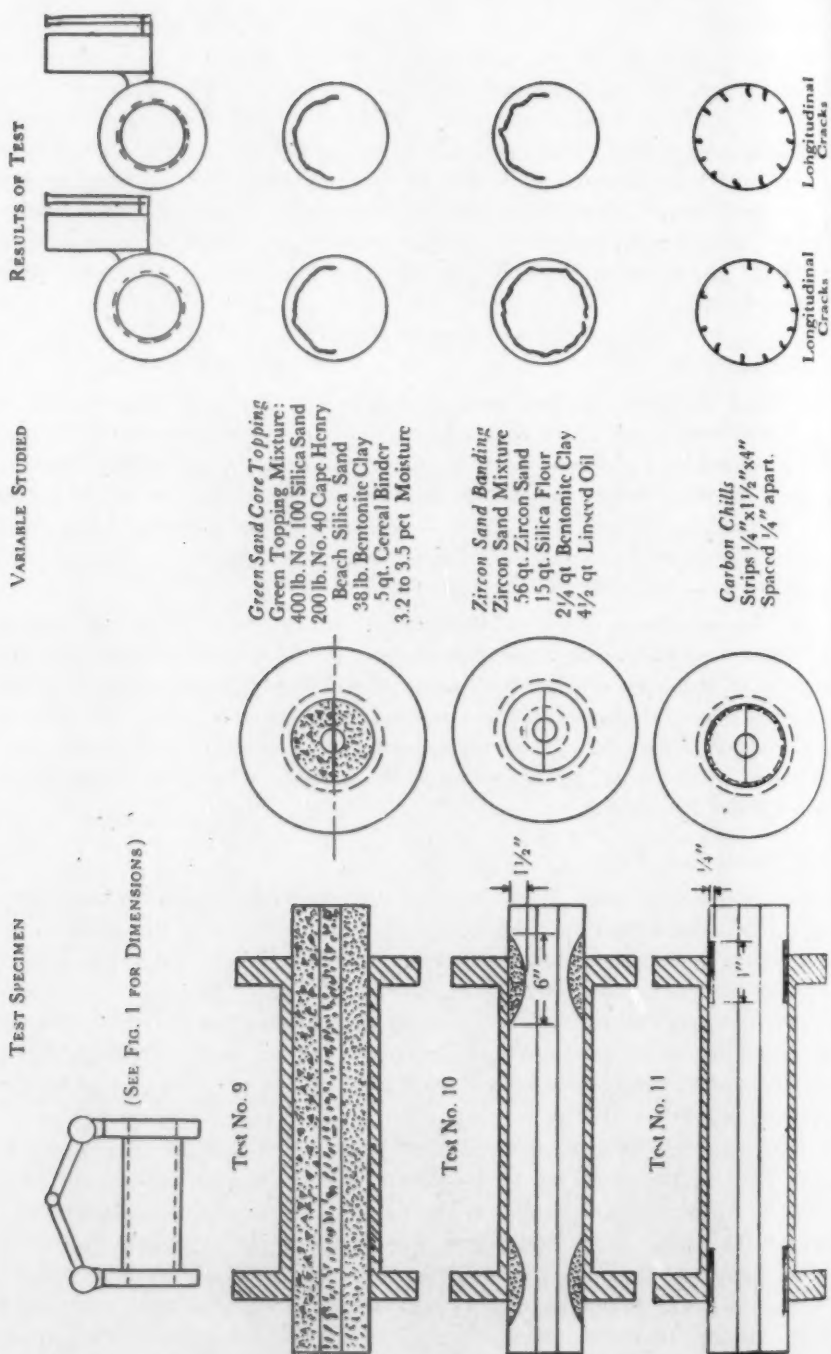
9. Four different locations for gates and riser placement were tested, as shown in Plates 2 and 3, for their effect upon bore-crack formation. All four locations have been observed in use at one time or another in foundries. Because of the high directional temperature gradient obtained, the method of gating and risering shown in Fig. 1, Plate 1, was adopted as standard for making flanged fittings at the yard. All of the test specimens shown in Plates 4 to 7, inclusive, were made by this method.

10. No correlation was found between any one system of gating and risering technique and the consequent location and extent of bore cracks. In the majority of instances, cracks were found almost completely around the circumference in one and almost half way around the other of a pair of flanges. It might be added that the cope metal appeared to be more prone to tearing than the metal in the drag, especially when the castings were gated through the risers (Plates 10 and 11).

### *Mold Stress Relieving*

11. In this connection, it was believed that the tendency toward hot tearing could be considerably diminished if the resistance offered by the mold to the contracting casting were sufficiently lowered. Accordingly, Tests 1 to 4 were repeated with one flange left off, as shown in Plates 3, 10 and 11, to permit the tube wall to pull in freely toward the one flange, unhindered by restraint from shoulders in the sand mold. The results obtained were surprising. Veins and bore cracks equally as severe as those produced in Tests 1 to 4 appeared in each of the four specimens.

12. Other stress-relieving methods (Tests 18, 19 and 20) also failed to lessen bore cracking. Test 18 employed pull-out boards set up vertically directly in front of and parallel to the flanges and risers. Immediately after pouring the boards were drawn out, thus enabling the sand in between the shoulder-obstructed extremities of the casting and the board cavity to collapse by cracking under the action of contraction stresses. Test 19 sought to reduce mold resistance by the employment of a fine-grained core sand mixture which,





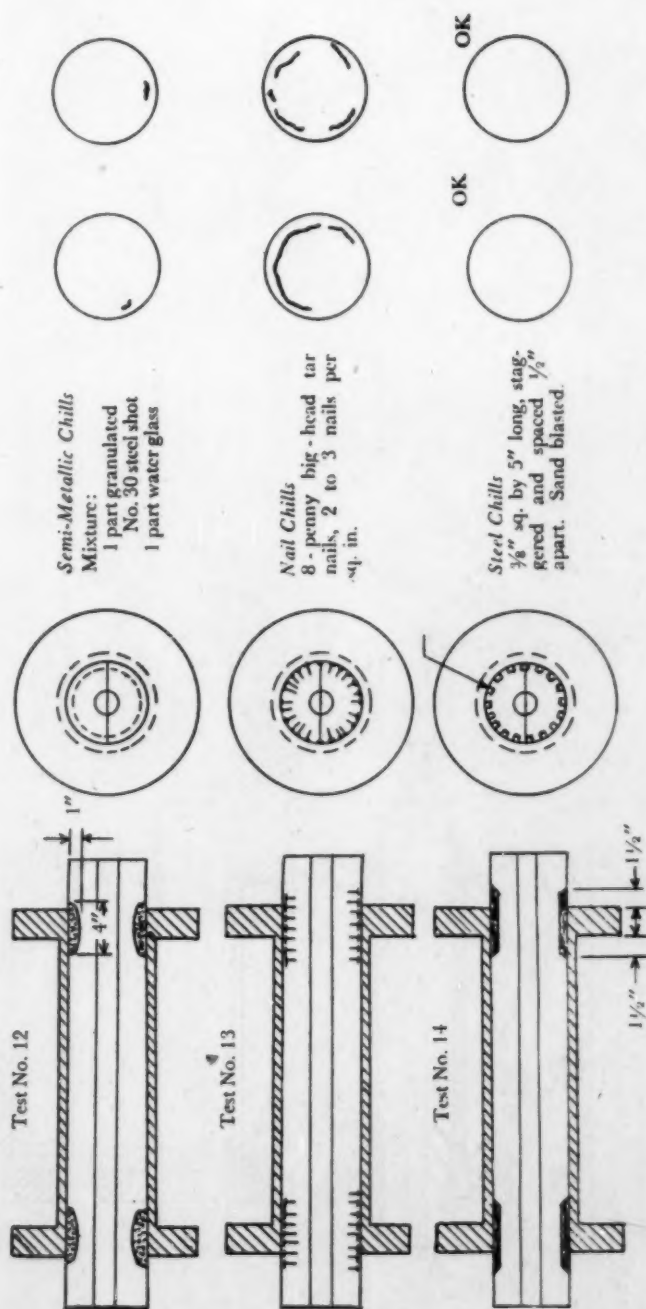
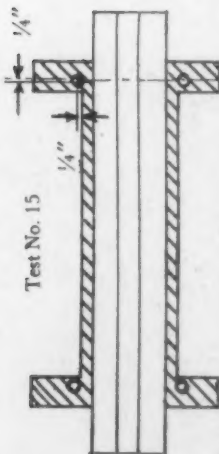
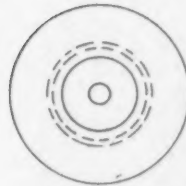

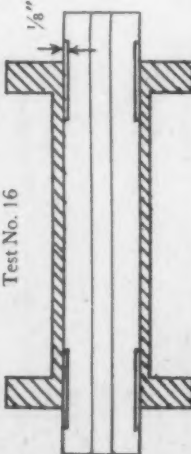


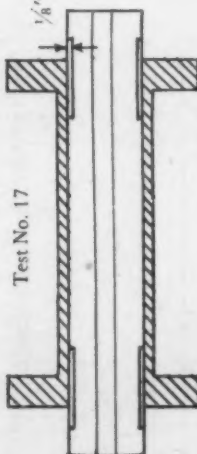


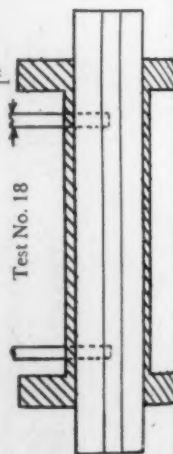




PLATE 4—EFFECT OF CHILLING METAL IN WAY OF FLANGES ON BONE CRACKING.

TEST SPECIMEN	VARIABLE STUDIED		RESULTS OF TEST	
<p>Test No. 15</p> 		<p><i>Internal Chill</i> <math>\frac{3}{8}</math>" dia. steel rod, sand blasted, positioned circumferentially as shown.</p>		
<p>Test No. 16</p> 		<p><i>Facing, Pipe Eliminator</i> 1 part pipe eliminator compound No. 1 1 part water glass</p>		
<p>Test No. 17</p> 		<p><i>Facing, Pipe Eliminator</i> 2 parts pipe eliminator compound No. 2 (carb-free) 1 part water 5 parts water glass</p>		
<p>Test No. 18</p> 		<p><i>Pull-Out Boards</i> Two boards, one in front of each flange and riser, were pulled out immediately after pouring to permit unhindered contraction.</p>		

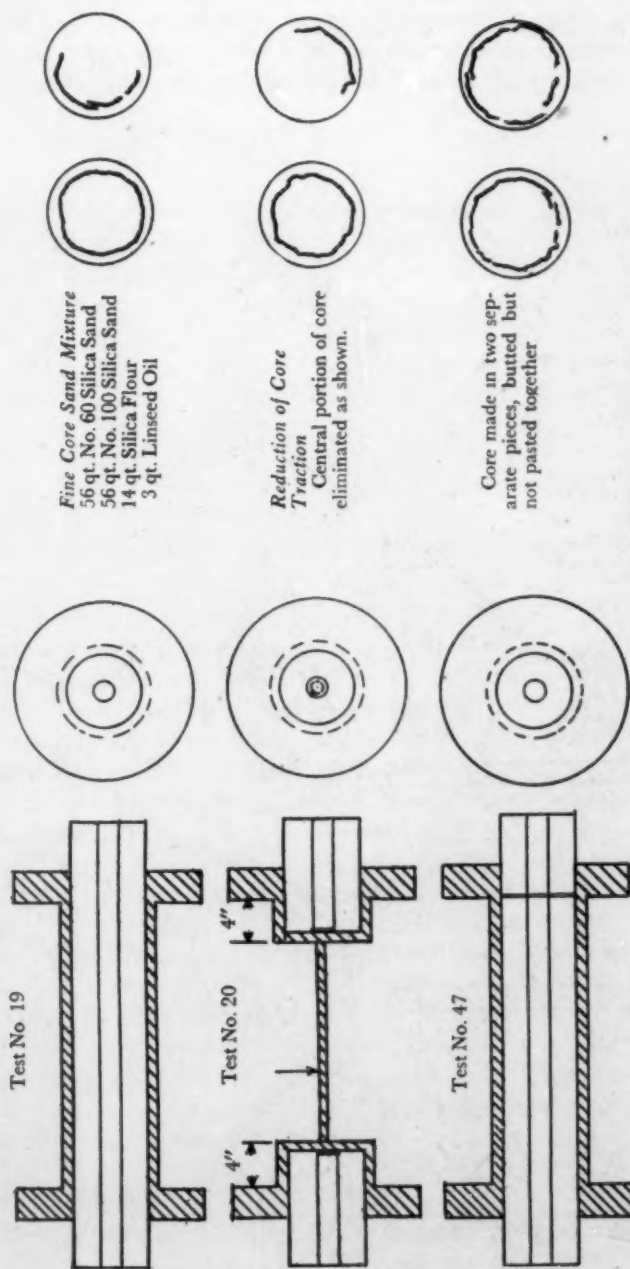


PLATE 5—EFFECT OF CHILLING, HEATING, MOLD RELIEVING, CORE TRACTION ON BORE CRACKING.

by reducing interpenetration of metal into sand interstices, would tend to reduce the grippage of one upon the other. Test 20, Plates 5 and 12, is unique in that it sought to eliminate as much as possible the effect of core friction by dispensing with the use of the central portion of the core. Bore cracks were

## DESIGN FEATURES

## RESULTS OF TESTS

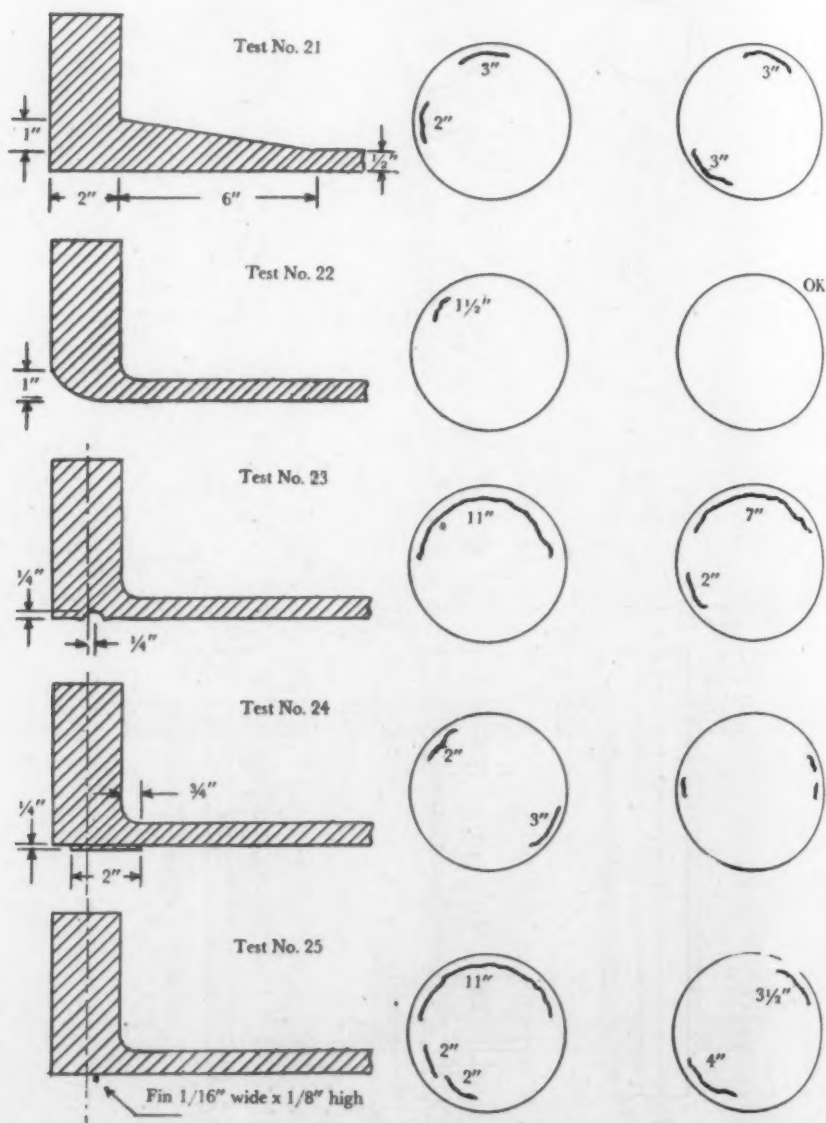


PLATE 6—INFLUENCE OF DESIGN ON BORE CRACKING.

found in all of the castings comprising this run of tests. The results of these tests would seem to indicate that the magnitude of mold resistance necessary to produce bore cracks is probably of a small order, as evidenced by the presence of bore cracks in castings employing as short a length of core, exclusive of the print, as 6 in.

### *Chilling*

13. Tests 9 to 15, inclusive, show the influence of various chilling agents upon the formation of bore cracks. Chills on all castings but one were applied externally by molding them into the core in way of the flanges. The mildest chillants applied were a bentonite-bonded green sand of A.F.A. Fineness No. 40, and Grade A<sup>1</sup> zirconite sand. The former, according to Briggs and Gezelius<sup>2</sup>, has a significantly higher heat transference rate than the finer grained sand (A.F.A. Fineness No. 60) which is this foundry's standard base for steel cores, while the latter not only possesses a still higher chilling power, due to its greater heat conductivity, but also has less than 1/3 of the thermal expansion of silica sand. The effect of other increasingly more potent chillants was likewise studied, namely, carbon (Test 11), semi-metallic mixture of 50:50 sand-steel shot (Test 12), nail heads (Test 13), and full metal chills (Test 14). As previously stated, one casting was fitted with an internal 3/8-in round wire chill in each flange, positioned in the plane where circumferential cracks were most likely to occur.

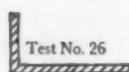
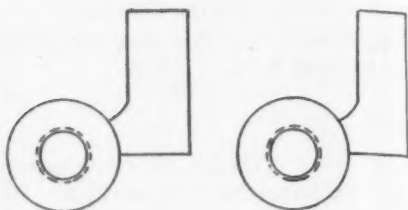
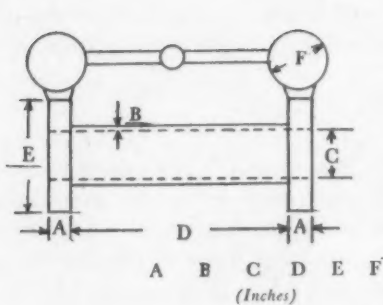
14. It is apparent from the results of the chilling tests that the action of only two chillants, namely, full metal chills and the 50:50 sand-steel shot mixture, was sufficiently severe to prevent bore cracking. Carbon chills of the design used in these tests are decidedly unsatisfactory. They not only cause severe longitudinal cracking of the metal along both long edges, but also serve to form numerous hard spots as a consequence of high carbon absorption by the metal. Semi-metallic chills employing granulated steel shot, though effective in preventing bore cracks, produce a very rough and deeply pitted surface (Plate 13). The dressing up of this surface by grinding often requires as much time and effort as is consumed in the excavation of the bore cracks. Incidentally, the elimination of bore cracks with semi-metallic chills is accomplished in part by early strengthening of the metal by chilling action, and in part by breaking up high local stress centralizations by providing many instead of a single or limited focal points for its action. Aside from insensibilizing the surface to notch effect, roughening also increases the effective surface area, and hence the cooling of the metal.

### *Retarded Cooling*

15. Not to overlook the effect of the reverse action, heating or retarded

<sup>1</sup> Pamphlet published by Titanium Alloy Mfg. Co., Niagara Falls, N. Y.

<sup>2</sup> Briggs, C. W., and Gezelius, R. A., "Studies on Solidification and Contraction in Steel Castings—III—The Rate of Skin Formation," *TRANSACTIONS, American Foundrymen's Association*, vol. 43, pp. 274-302 (1935).



Test No. 26

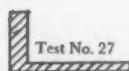
$\frac{1}{2}$     $\frac{1}{2}$    7   24   15   2



Completely Through

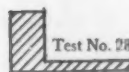


Completely Through



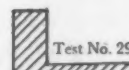
Test No. 27

1    $\frac{1}{2}$    7   24   15   4



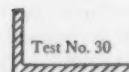
Test No. 28

2    $\frac{1}{2}$    7   24   15   6



Test No. 29

2    $\frac{3}{4}$    7   24   15   6



Test No. 30

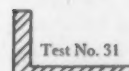
$\frac{1}{2}$    1   6   24   15   2



Longitudinal



Longitudinal



Test No. 31

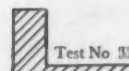
1   1   6   24   15   4



Completely Through

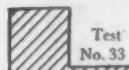


Longitudinal



Test No. 32

2   1   6   24   15   6



Test No. 33

4   1   6   24   15   8



PLATE 7—INFLUENCE OF GEOMETRY OF FITTING ON BORE CRACKING.



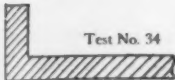


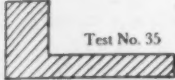


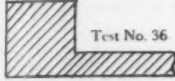


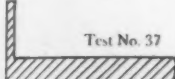


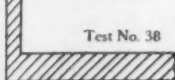


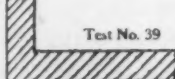


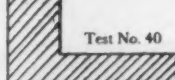


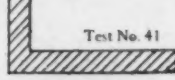


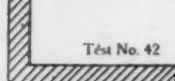


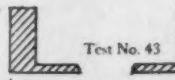


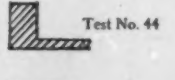


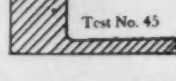


	A	B	C	D	E	F		
	(Inches)							
 Test No. 34	1 1/2	1 1/2	7 1/4	24	15	6	 OK	
 Test No. 35	3	1 1/2	7 1/4	24	15	8	 OK	 OK
 Test No. 36	4 1/2	1 1/2	7 1/4	24	15	8		
 Test No. 37	1/2	2	4 1/4	24	15	4	 Longitudinal	 Longitudinal
 Test No. 38	3/4	2	4 1/4	24	15	4	 Longitudinal	 Longitudinal
 Test No. 39	2	2	4 1/4	24	15	6		
 Test No. 40	4	2	4 1/4	24	15	8		 OK
 Test No. 41	1 1/2	1 1/2	7 1/4	12	15	6	 OK	 OK
 Test No. 42	1 1/2	1 1/2	7 1/4	24	17	6		 OK
 Test No. 43 72"	2	1/2	7 1/4	72	15	6		
 Test No. 44	2	3/8	2	32	6	4		
 Test No. 45 Cast flatwise, flange up	4	1	36	18	46	*		

PLATE 8—INFLUENCE OF GEOMETRY OF FITTING ON BORE CRACKING. \*

cooling, Tests 16, 17 and 46 were made. In Tests 16 and 17, instead of chilling the metal in way of the flanges, additional heat—evolved from the exothermic reaction of the anti-piping compound material inlaid on the core—was applied to retard the normal rate of cooling of the metal. Examination of the test castings (Plate 14) disclosed, in the case of Test 16, a noticeable diminution in the extent of bore cracking, while in the case of Test 17 no reduction was noted. There was a greater roughening of surface metal in the former (Test No. 16). A greater proportionate quantity of anti-piping was likewise used in making the core for Test 16. Whether the roughening, or the greater quantity of heat evolved, or both, account for the reduction of bore cracking in the one over the other is not known.

16. Both of the foregoing preparations are difficult of application without peeling, spalling, or cracking of the coating.

17. Test 46 employed atmosphere control in the mold, using propane gas after the manner of Dietert<sup>1</sup>. The gas was ignited 5 min. prior to pouring and continued burning until 5 min. after pouring was completed. In the period preceding pouring, the surface sand in the mold cavity attained a minimum "tempil" temperature of 200° F. Preheating the mold in this, or in a similar manner, does not abate cracking. The only discernible difference between retarded cooled and normally cooled castings is in the location of the cracks. Those in the retarded cooled specimens are consistently displaced further back into the bore, almost into the plane of the back face of the flange. This same displacement was also noted when the heat at the flanged ends was derived

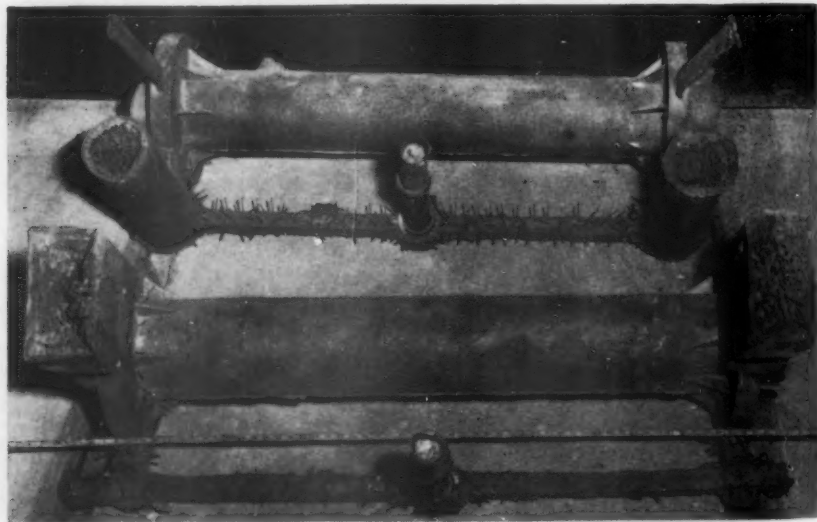


PLATE 9—SPOOL FITTING, LONG BARREL, TWO METHODS OF GATING AND RISERING

<sup>1</sup> Dietert, H. W., Doelman, R. L., and Bennett, R. W., "Mold Atmosphere Control," *TRANSACTIONS, American Foundrymen's Association*, vol. 52, pp. 1053-1077 (1944).

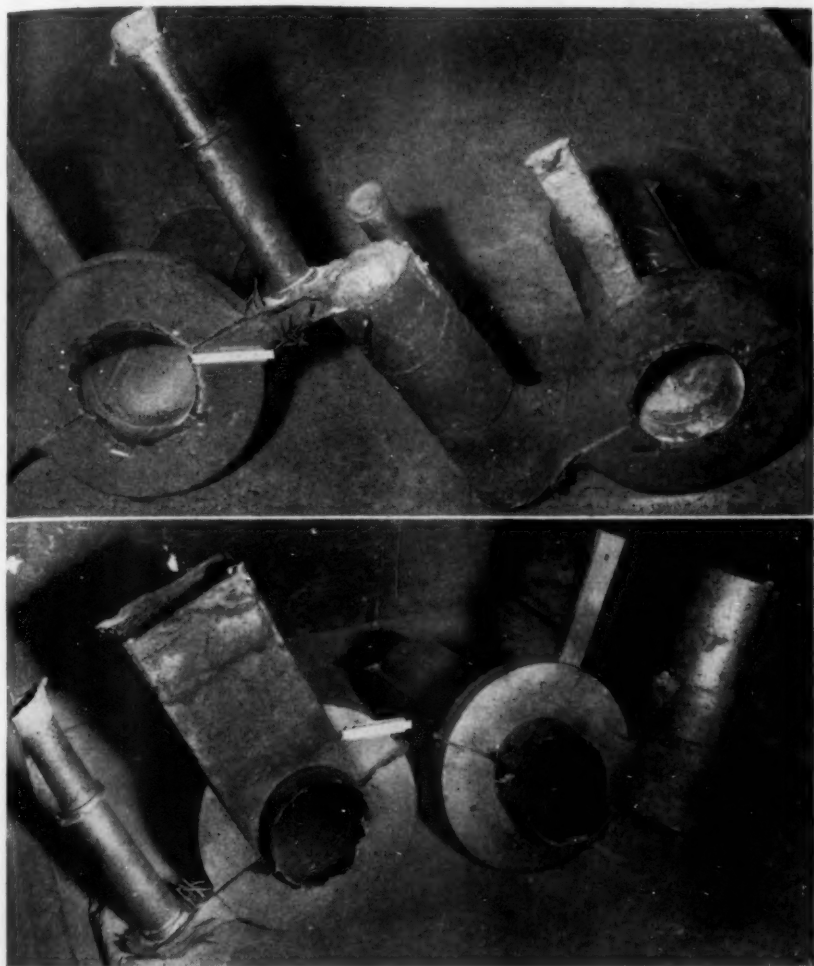


PLATE 10—TOP—SINGLE-FLANGE FITTINGS, SHOWING POWDER INDICATIONS IN BORE. PLATE 11—BOTTOM—SINGLE-FLANGE FITTINGS, SHOWING VEINS IN TWO DIFFERENTLY GATED AND RISERED SPECIMENS.

from internal and external pads of metal, as illustrated in Tests 24 and 21, respectively.

18. Last but not least, Test 47 was executed in order to prove that bore cracks were neither associated with, nor caused by core cracking. Instead of using a single continuous length of core, two separate pieces, one long and one short, were made and independently set in the mold, each butting the other in a closed (not pasted) butt joint. The joint made up approximately in the location where bore cracks occur. Bore cracks, with the characteristic veining associated with them, developed under both flanges. The line of failure and

veining followed its own course without appearing to have been either attracted, repelled, or in any way influenced at any point by the plane of separation in the core.

### *Design*

19. Plate 6 illustrates five different designs for flanges, each succeeding the other in the order of their conception and manufacture. Two of the designs avail themselves of added metal in external and internal padding (Tests 21 and 24); and two, of subtracted metal contoured in the shade of a bell's mouth (Test 22), and a shallow "U" groove (Test 23) whose depth is within the tolerance range of fairing allowed for excavation without subsequent filling. Test 25 utilized a notch  $\frac{1}{4}$ -in. deep cut in the core, which resulted in the formation of a fin simulating a vein in the location where vein-capped bore cracks ordinarily occur.

20. Of the padded designs, the pad in the bore gave the better results. The external padding merely shifted the plane of cracking further back into the bore without apparently affecting either the lineal dimensions or depth of the crack. In the case of the bore padding, the depth of the cracks decreased to less than  $\frac{1}{4}$  in., and the entire crack was found lifted from the wall into the pad itself, as shown in Plate 15. The results obtained with the bore padding were checked on several castings for consistency. In all instances, bore failure was confined wholly to the padding.



PLATE 12—SHOWING POWDER INDICATIONS IN FITTINGS — LEFT — HAVING NO CENTER CORE — RIGHT — "U-GROOVED" DESIGN IN BORE.

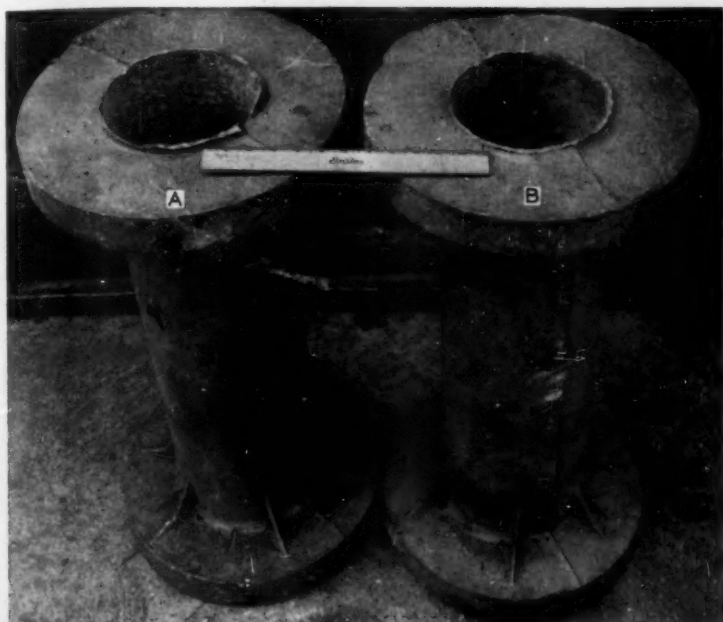


PLATE 13—TOP—MAGNETICALLY TESTED—A—NAIL HEAD CHILLING, B—SEMI-METALLIC CHILLING. NOTE CRACK IN A.

PLATE 14—BOTTOM—MAGNETICALLY TESTED—A—ANTI-PIPING COMPOUND NO. 1 APPLICATION, B—ANTI-PIPING COMPOUND NO. 2 APPLICATION.



PLATE 15—MAGNETICALLY TESTED, PARTIALLY CHIPPED, INTERNAL PADDING IN BORE. NOTE CRACK IN PAD AND NOT IN BARREL AFTER CHIPPING.

21. The localization of the cracking in the padding proper rid the casting of its defects upon removal of the padding. Pad removal from the bore is accomplished expeditiously either with chipping or machining. This is much easier and less time consuming than the excavations performed on the unpadded bore, or in the use of chills after the manner of Test 14. As of now, in the author's opinion, padding is the most effective way of dealing with bore cracks. Whether the same efficacy of results will obtain elsewhere is dependent upon the depth of currently occurring cracks. Deeper cracks than those encountered in the subject tests may require slightly thicker padding, and vice versa.

22. Of the two subtracted metal designs, the bell mouth gave the sounder metal. However, this design has the disadvantage of lower mechanical strength. Furthermore, it increases the cost of making core boxes and complicates the making and the accurate setting of cores.

23. Concerning the grooved bore, the re-entrant recess forming the groove creates a hot-spot condition which is wont to invite cracks. From the design standpoint, it, too, is unsatisfactory, for it interrupts the smooth transmission of tensile stresses, causing them to hump under it and thus raising them to a



high, unsafe value in the area of the root. It will be recalled that it takes but a very small value of stress to rupture steel at the high temperatures at which hot tears occur.

24. Notching the core, as was done in Test 25, had no effect upon either localizing or diminishing the extent of bore cracking. If the veins which are associated with bore cracks are instrumental in their formation, then a fin artificially produced to simulate a vein in the region of the rupture line should, in like manner, serve to localize the failure within itself. Such was not the case, for the fin had not the slightest visible effect upon the phenomenon studied. Veins formed as usual alongside and across the fin as though it were not there.

#### *Influence of Geometry*

25. Preliminary tests run on different designs of fittings showed that not all of them were subject to bore cracking. It was noted that the wall-flange thickness ratio exerted a manifest effect on the extent of bore cracking. Accordingly, the following geometrical relationships were studied:

(a) Wall thickness maintained constant at  $\frac{1}{2}$ , 1,  $1\frac{1}{2}$  and 2 in., flange thickness was varied from  $\frac{1}{2}$  to  $4\frac{1}{2}$  in. (Tests 26-40).

(b) Flange thickness maintained constant at  $\frac{1}{2}$ , 1, 2, 4 and  $4\frac{1}{2}$  in., wall thickness was varied for each from  $\frac{1}{2}$  to 2 in. (Tests 26-40).

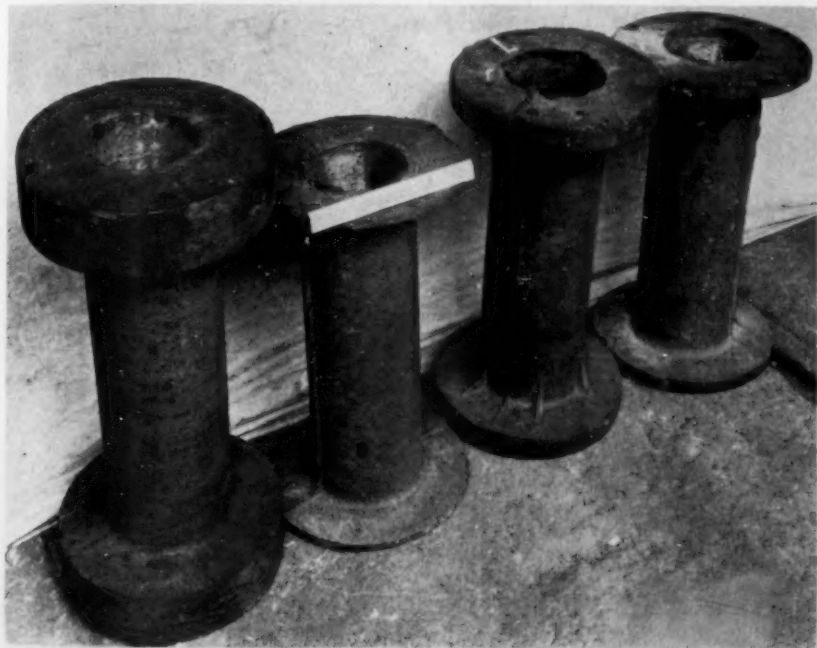


PLATE 16—MAGNETICALLY TESTED, SHOWING DIFFERENT THICKNESSES OF FLANGES (TESTS 33, 26, 32, 27).  
NOTE POWDER INDICATIONS.

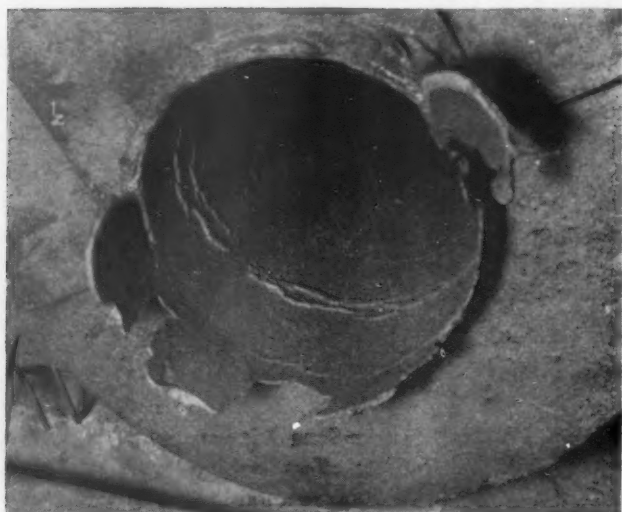


PLATE 17—CLOSE-UP VIEW OF VEINING.

- (c) All elements remaining constant, flange height was varied from 15 to 17 in. (Tests 41 and 42).
  - (d) All elements remaining constant, length of barrel was varied from 24 to 72 in. (Tests 28 and 43).
  - (e) Bore diameter was varied from 2 to 36 in. (Tests 44 and 45).
26. The results of geometry factors are summarized as follows:
- (1) With flanges  $\frac{1}{2}$  to 1-in. thick, but thinner than the wall, longitudinal cracks developed in the drag half the full length of the fitting. The thinner these flanges for a given wall thickness, the more pronounced were the longitudinal cracks.
  - (2) With flanges  $\frac{1}{2}$  to 1-in. thick, affixed to bodies of equivalent wall thickness, a slight tendency to longitudinal cracking still remained. The prevailing type of failure, however, was a severe circumferential cracking both inside the bore and outside in the flange fillet.
  - (3) With flanges 1 to  $2\frac{1}{2}$ -in. thick, conjoined to bodies having  $\frac{1}{2}$  to  $\frac{1}{4}$  the thickness of the flange, the fittings developed bore cracks almost the full perimeter of the bore.
  - (4) With flanges  $1\frac{1}{2}$  to  $4\frac{1}{2}$ -in. thick, fittings which had comparatively heavy wall thicknesses, ranging from  $1\frac{1}{2}$  to 2-in. thick, showed almost complete freedom from bore cracks, while those which had thinner wall thicknesses, ranging from  $\frac{1}{2}$  to 1-in. thick, developed partial cracking of the bore.

#### *Influence of Chemistry*

27. In this study only three compositions of steel were investigated (paragraph 7). All three exhibited bore cracks, the austenitic steel—much to the authors' surprise—more so than the other two (Plate 18). Although no test castings were made of carbon-molybdenum steel, it, too, is vulnerable to bore

cracking. Abundant evidence of their occurrence in this kind of steel is contained in our inspection files on magnetically tested fittings made in the course of production.

28. Lutts and Hickey<sup>1</sup>, who made a statistical study of bore cracks on hundreds of flanged castings, concluded that chemistry has a definite influence on bore cracking. Not having made a large number of castings of either a particular design or composition, the authors advance no comment on this point.

#### *Mechanism of Formation*

29. Solidification is a continuously changing phenomenon, showing in its early stages the simultaneous existence of dissimilar states of matter in dissimilar thicknesses of multi-thickness castings. If the progress of solidification and cooling could be arrested but for only a moment for scrutiny at the instant when the last liquid metal in the wall of a flanged fitting had frozen solid, the condition of the metal obtained in the wall-flange juncture would approximate in appearance that developed in Plate 20. Study of this sketch, together with Plates 18, 19 and 21, discloses the following pertinent facts relative to the mechanism of bore cracking:



PLATE 18—FLANGE-WALL CROSS SECTION, CORROSION RESISTING STEEL. CRACK IS IN ENCIRCLED AREA. NOTE THE ORIENTATION OF PRIMARY GRAINS AND THE SHARP MIDDLE LINE IN THE WALL WHICH DIVIDES OUTSIDE FROM INSIDE CRYSTALLIZATION. MACROETCHED IN  $\text{HCl-HNO}_3$ .

<sup>1</sup> Lutts, C. G., and Hickey, J. P., "Special Low Carbon Steel for Castings," TRANSACTIONS, American Foundrymen's Association, vol. 52, pp. 904-912 (1944).

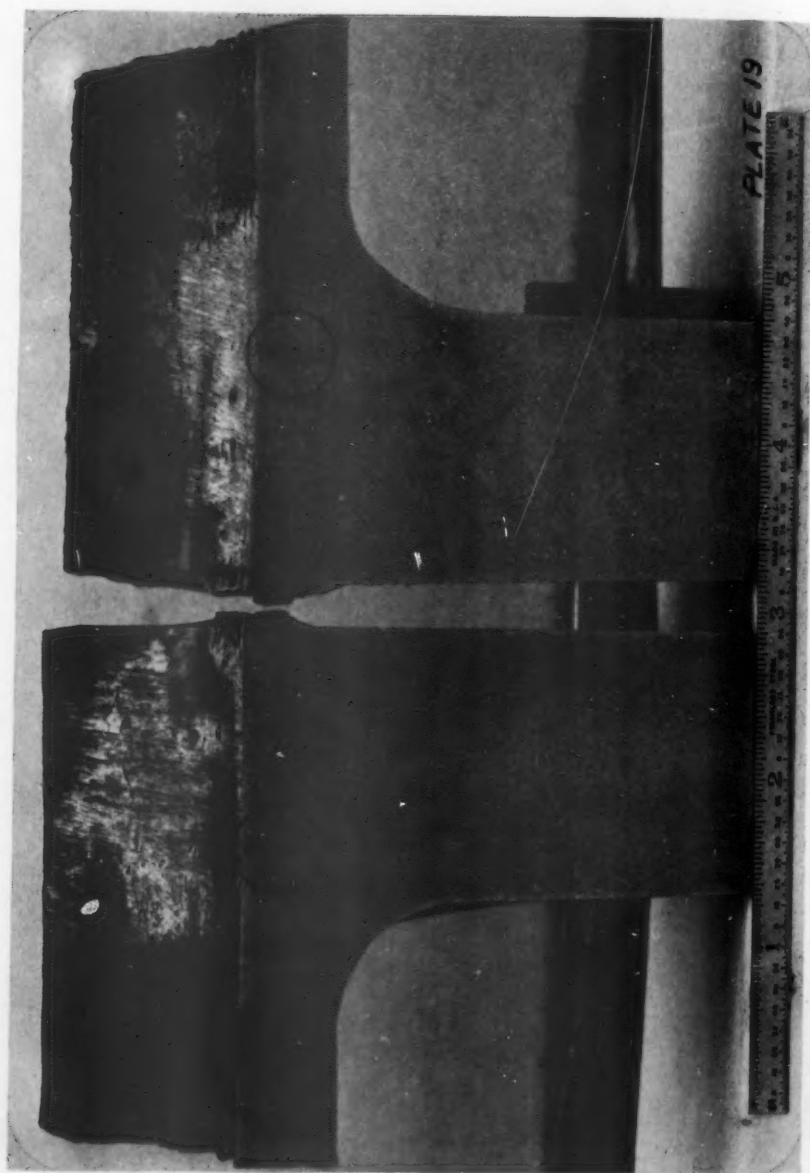


PLATE 19—FLANGE-WALL CROSS SECTION, MEDIUM CARBON STEEL, MACROETCHED WITH 10 PER CENT AMMONIUM PERSULFATE SOLUTION.

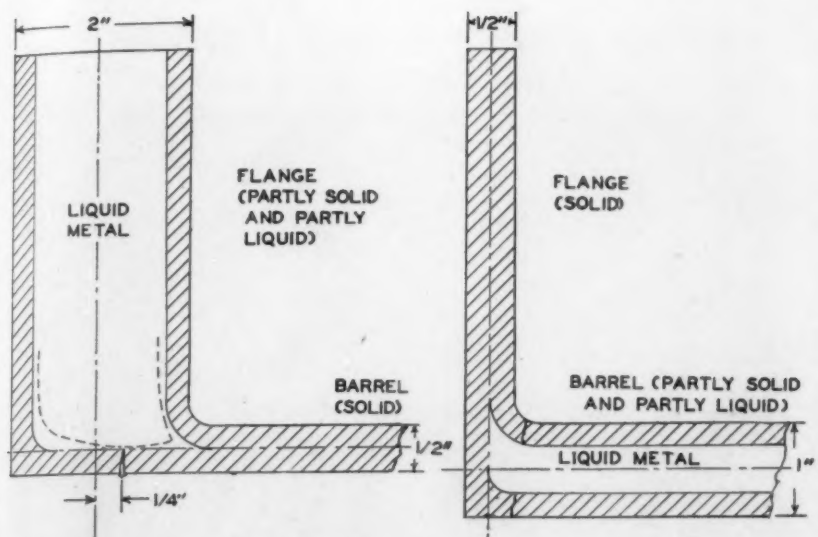


PLATE 20—SKETCH SHOWING PROBABLE CONDITION OF METAL IN THE FLANGED END OF TWO DIFFERENT CASTINGS, APPROX. 1 TO  $1\frac{1}{2}$  MIN. AFTER POURING. CROSS-HATCHED AREAS REPRESENT SOLIDIFIED METAL; BLANK WHITE AREAS REPRESENT LIQUID METAL.

(1) At the instant under consideration, the thinnest shell of solidified metal in the wall-flange cross section is located approximately midway between the center and back face of the flange. The following influences deterred thickening at this point:

- (a) Excessive heat from the large volume of metal (latent heat of fusion equals 100 Btu. evolved per lb. of steel frozen, the outflow of which determines the rate and direction of solidification).
- (b) High volume to surface area ratio (approx. 1 cu. in./sq. in. as against 0.25 cu. in./sq. in. in the wall).
- (c) Lower cooling capacity of the core as compared with that of the green sand in the mold.
- (d) Corners' effect (entrant and re-entrant) which displaced the point of slowest cooling in the direction of the re-entrant angle.

(2) It necessarily follows, after the manner of a corollary, that the location of the thinnest wall metal is also the location of the hottest metal.

(3) The dendritic form of solidification leaves interdendritic channels perpendicularly oriented with respect to the walls of the container. The normal disposition of the peripheral dendrites shown in the macrostructure of Plates 18 and 21 makes for weakness across the grains.

(4) Weakness of the section at this point is ostensibly due to thinness of section, hotness of metal, unfavorable orientation of crystallographic planes.

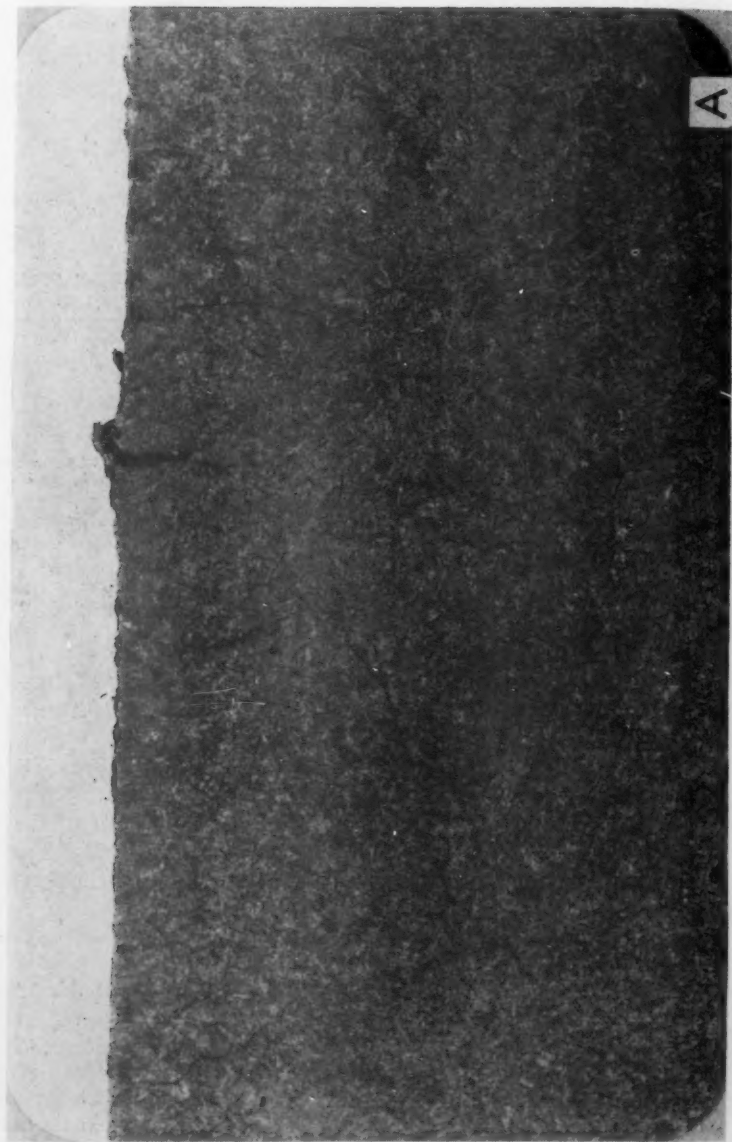


PLATE 21—A—MACROSTRUCTURE OF METAL CONTAINING BORE CRACK. CRACK IS CAPPED WITH METAL VEIN. ETCHED WITH AMMONIUM PERSULPHATE. ( $\times 4\frac{1}{2}$ ).  
(Continued on following page)



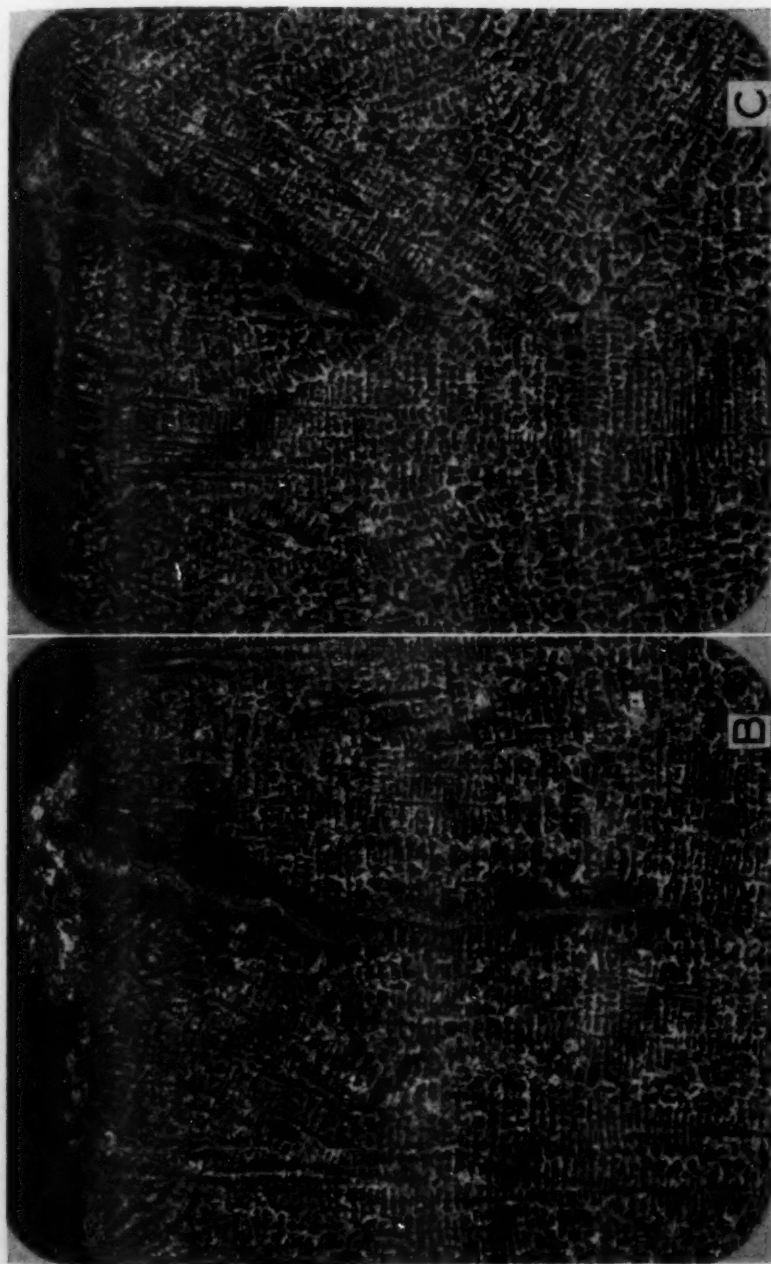


PLATE 21—(Continued from preceding page)—B—MACROSTRUCTURE OF BORE CRACK AND VEIN. NOTE THE INTERGRANULAR PATH OF FAILURE. ( $\times 10$ ). C—ANOTHER BORE CRACK. IT, TOO, IS LOCATED BETWEEN THE DENDRITES. ETCHED WITH AMMONIUM PERSULPHATE. ( $\times 10$ ).

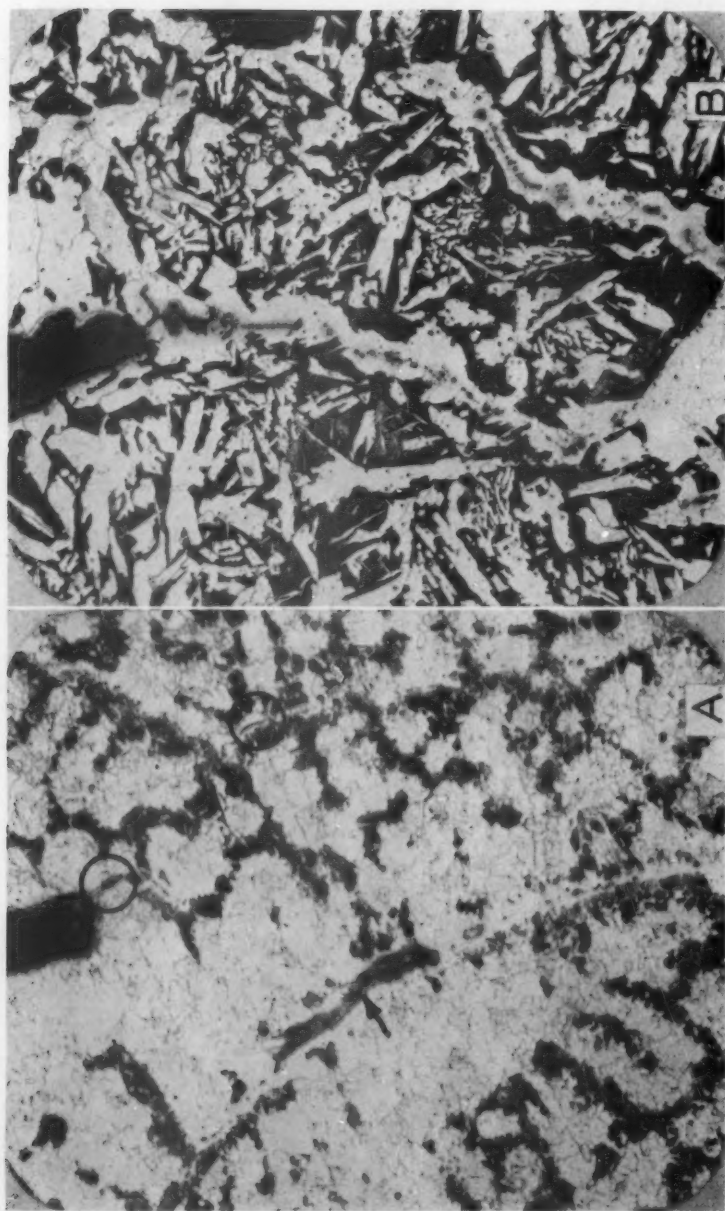


PLATE 22—MICROSTRUCTURE AT ROOT OF BORE CRACKS IN TWO DIFFERENT CASTINGS. BLACK AREAS ARE PEARLITE; WHITE AREAS ARE FERRITE. NOTE THE PRESENCE OF LENTICULAR SONIMS AND THE BEADLIKE ARRANGEMENT OF OTHERS IN THE FERRITE CHANNELS, WHICH INDICATES EITHER CAPILLARY FLOW OF METAL IMMEDIATELY PRIOR TO FREEZING, OR AN ABNORMAL ENRICHMENT OF LOW-MELTING-POINT CONSTITUENTS IN THE LAST LIQUID TO FREEZE. NO CHAINS OR ELONGATED SONIMS WERE FOUND IN AREAS REMOVED FROM THE CRACKS. NITAL ETCHED. ( $\times 75$ ). (Continued on following page).

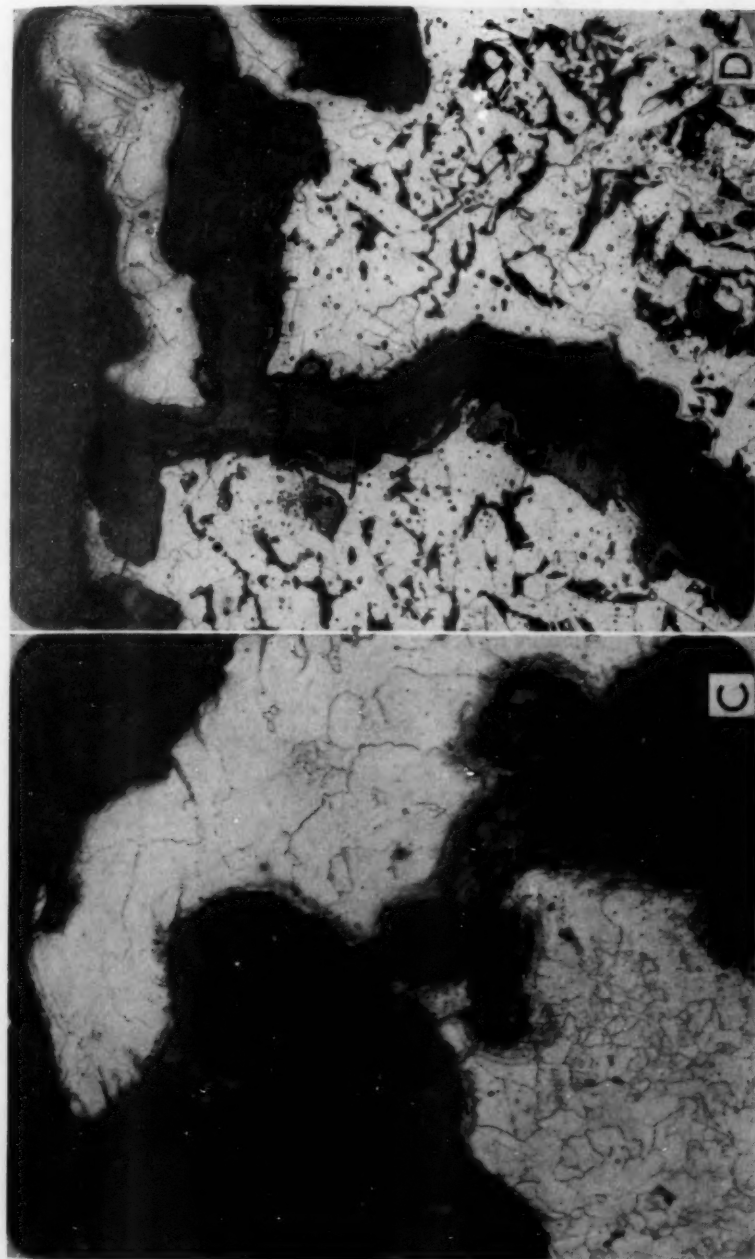


PLATE 22—(Continued from preceding page).—Microstructure at Mouth of Cracks Shown in A and B. Note the Extent of Decarburization. Also, the Entrapped Slag (D). Slag is Also Evident in C, Adhering to the Sidewalls. The Gray Material in the Center of the Crack is Bakelite Mounting. Nital Etched. ( $\times 100$ ).

(5) Weakness of the section constitutes only one-half of the cause for bore cracking. The other half of the cause are the stresses engendered in the process of solidification, namely:

(a) Hoop contraction stresses.

(b) Longitudinal contraction stresses.

(6) Conversely, the core expands circularly and lengthwise, thus bucking the foreshortening and enclosing of the casting.

(7) The hindrance offered the casting by the expanding core is productive of multi-axial tensile stresses in the casting of a sufficient order of magnitude to tear the casting either longitudinally or circumferentially of the bore, depending on the geometry of the flange section which, in turn, governs the location of the weakest metal.

30. Any explanation of bore cracking must also account for the appearance of the veins (Plate 17) which are associated with bore cracks. The following observations on veining will prove helpful in explaining their formation.

(1) Veins are ridges of carbonless iron admixed with slag running alongside bore cracks (Plates 21 and 22).

(2) Bore cracks are seldom found directly under the veins. They usually are located immediately in front of and at the foot of veins.

(3) The external form of veins is rarely symmetrical. They have the appearance of having been slightly rolled back, while still hot, by the relative movement of casting and core.

(4) Not all veins conceal cracks (Plate No. 24).

(5) Wide, gaping tears seldom exhibit veining.

(6) The metal bordering bore cracks almost always shows some evidence of decarburization. Not infrequently, tag ends and stringers of elongated inclusions are apparent in channels of ferrite. The lenticular character of inclusions at the mouth of tears is most significant. It would appear that capillary flow of metal through a tight crevice produced this extension of non-metallics. Subsequent freezing trapped them in situ while en route to the outside.

(7) Cracking of the core, if any does take place, is not productive of veins. Test 47, employing a core cut in two in way of the flange, and with both ends abutting each other, showed no vein over the interface. However, veins did form, uninfluenced by the core crack, in a location of their own choosing.

31. Based on the foregoing observations, the following explanation of bore cracking is tendered provisionally, and is subject to alteration or amendment whenever the observations of others appear inexplicable or irreconcilable with its views.

32. Bore cracks are hot tears which are formed early in the solidification of steel by multi-axial stresses, predominantly tensile in character, arising principally from the thermal contraction of a differentially cooling steel casting onto an enclosed and expanding sand core. By reason of mold restraint, these stresses are transmitted across the cross section of the barrel to the fulcrum of the stress system, viz., the face of the flange. The ability of the hot metal in the area under the flanges to transmit these stresses at the instant the thinner

wall of the casting has completely solidified is inadequate, and, therefore, productive of failure. Limiting the depth of propagation of failure inwards is the solid-liquid interface.

33. Veins are extrusions, apparently of capillary origin, of iron (decarburized steel) and iron oxide. Physical forces set up in solidification, such as internal gas pressure and contraction effects, also can influence the movement



PLATE 23—MICROSTRUCTURE ALONG BORE CRACK, BOTTOM PORTION. NOTE THE ENTRAPPED IRON OXIDE AND THE LOSS OF PEARLITE BY DECARBURIZATION. NITAL ETCHED. ( $\times 100$ ).





PLATE 24—MICROSTRUCTURE OF CROSS SECTION OF VEIN AND OF METAL DIRECTLY UNDERNEATH SHOWING ABSENCE OF TEARING. NOTE THE STRINGER INCLUSIONS WHICH MARK THE CHANNEL OF METAL FLOW. THE CHANNEL, ON COOLING, FUSION-WELDED ITSELF CLOSED. NITAL ETCHED. ( $\times 75$ ).

of the remaining liquid of low melting point through these cracks. The probable source of the iron and iron oxide is explained as follows:

Contemporaneously with the hot tearing of the metal, oxidation of the steel by the oxygen contained in the mold gases asserts its action. In the initial stages of this reaction, carbon is preferentially attacked before iron, leading to decarburization of the fractured surfaces, and then of the capillary flowed metal. The iron is next attacked, resulting in the formation of iron oxide, which, as the photomicrographs



show, is found admixed with the iron in the vein and also adhering to the sidewalls of the crack.

Slight local reaction must, of necessity, exert slight local effects. Oxidation of the carbon (decarburization), therefore, must raise the melting point of the decarburized steel to that of pure iron, while the oxidation of the iron (slagging) must evolve heat of formation of iron oxide. The former action would tend to immobilize the bleeding metal, whereas the latter would tend to raise the temperature of the slag, thereby rendering it more fluid and more penetrating of the sand. Conditions being favorable, it is thus possible for cracks to close themselves completely by feeding of filler metal from the interior. Attesting to this fact is the occasional absence of cracks under some veins.

#### SUMMARY AND CONCLUSIONS

34. Bore cracks are hot tears which occur on the inner surface of the heavier of two dissimilar sections conjoined perpendicularly with one another. They differ from those commonly found in fillets and re-entrant corners of sharply dissimilar sections in that they have narrower width and are always capped with metal veins.

35. The geometry of section most favorable for the development of bore cracks is one having a flange-to-wall-thickness ratio of approximately 2 to 1, with a value for the latter of less than one in. (paragraph 26).

36. From these experiments it appears that in order to overcome bore cracking either the stresses impressed upon the casting must be sufficiently alleviated, or the metal hot-strengthened compositionally, or with chilling, or wall thickening. As of today, there are two practical methods in use in this foundry for overcoming bore cracks: chilling of the metal in way of the flange with metal chillers after the manner of Test 14, Plate 3; bore padding of the metal in way of the flange in the manner shown in Test 24, Plate 6. The second method merely lifts the bore cracks into the pad, which is subsequently removed. Other less effective methods are shown in Tests 16 and 12, Plates 5 and 4, respectively.

#### DISCUSSION

*Presiding:* T. N. ARMSTRONG, International Nickel Co., Inc., New York, N. Y.

**CHAIRMAN ARMSTRONG:** Mr. Brinson, can you tell us how to avoid bore cracks? Some of your sketches showed that there were no bore cracks present.

**MR. BRINSON:** I cannot, but we have found that, from 2 in. up to 15 or 18 in., the size of the bore has nothing to do with bore cracks, but we believe that the relation between the wall thickness and the flange thickness will affect the condition.

**E. C. TROY:** We have found, when changing wall-flange relations, that while the first sample might be free of cracks, the second sample often showed the defect.

**MR. BRINSON:** We had no exact duplications. However, we have not had time to investigate all of the conditions we encountered.

<sup>1</sup>Dodge Steel Co., Philadelphia, Pa.

MR. TROY: What is your objection to chilling as a routine method of overcoming bore crack difficulties?

MR. BRINSON: In this particular test, we were willing to try everything. We are, at the present time, using chills as a means of overcoming the difficulty from a ductility point of view. We do not necessarily believe that it is a cure. Chilling has to be watched just the same as anything else. I had some experience with chilling a large 15-in. battleship fitting about 12 yr. ago. We got the bore crack and we did not know what it was. We tried chilling, and the crack just moved down about 15 in. to the end of the chills. Then we started in staggering the ends of the chills and succeeded in removing the crack, so we do know that chilling is a remedy.

H. F. TAYLOR<sup>2</sup>: The Naval Research Laboratory has made at least 1000 experimental castings on this job and can verify about 90 per cent of what Mr. Brinson has said. As Mr. Lutts\* points out, the low-carbon steel with increasing manganese content seems to cut down the incidence of this defect. We looked into that quite carefully and find that it is true that as the manganese increases, the incidence and magnitude of this bore crack becomes less and less. We have found that it takes from 3 to 4 per cent manganese in a low-carbon steel to eliminate this condition. We also have made experiments which indicate that stainless steels are relatively free from this trouble.

MR. DUMA: We have concluded tentatively that bore cracks are hot tears formed early in the solidification of the casting by stresses, multi-axial stresses, which are predominantly tensile in character. The stresses are generated by the casting contracting onto an expanding core, and the failure takes place at the weakest spot, which weakest spot happens to be the location shown in the photographs and sketches. It is off center, drawn from the center line of the flange inwards by the slower-cooling reentrant corners, and if we could plot the solidification curve in that section one min. after pouring, we probably would find that the thinnest cross section of hottest solidified metal would be located exactly at this point. In the presence of an oxidizing atmosphere in the mold, oxidation of the torn surface occurs, the oxide and molten metal bleeding out into the bore and forming a vein which caps the entire length of the crack.

Taking that as a tentative theory, I believe that I can explain why Mr. Lutts'\* manganese additions have tended to suppress the formation of bore cracks. Low-carbon contents have raised the solidification point of the steel considerably and, in addition, manganese has imparted hot strength to the metal. These two physical facts serve to strengthen the metal sufficiently to resist tearing as it passes through its critical tearing-temperature range.

Regarding Mr. Taylor's observation on the relative freedom of stainless steels from bore cracks, we have noted to the contrary that they (18 per cent chromium—8 per cent nickel) are almost equally as prone to the defect as is medium carbon steel, developing cracks equally as deep and exterior veining equally as prominent.

<sup>2</sup>Naval Research Lab., Anacostia Sta., Washington, D. C.

\*Lutts, C. G., and Hickey, J. P., "Special Low-Carbon Steel for Castings," TRANSACTIONS, American Foundrymen's Association, vol. 52, pp. 904-912 (1944).

## Design of Test Coupons for Cast Steel†

By R. C. WAYNE\*, H. F. BISHOP\* AND H. F. TAYLOR\*, WASHINGTON, D. C.

### Abstract

*Several test coupons of various designs were cast in steel, and their relative merits in producing satisfactory blanks for tensile tests were compared on the basis of mechanical properties and economy of yield. Coupons of the cloverleaf type in which the tensile blanks are spaced around a central section not only give properties equal to or better than those of other more conventional types, but require much less riser metal per specimen. The blanks may be readily removed by a cold saw or torch. The use of necking cores for facilitating removal of blanks from coupons was investigated and showed some promise of utility. The meaning and limitations of coupon testing are discussed briefly.*

### INTRODUCTION

1. The object of this work was to develop a test coupon for cast steel to meet the following requirements:

- (a) *Soundness*: The specimen blanks must be uniformly sound without centerline shrinkage or other defects attributable to the mold design.
- (b) *Ease of Molding*: The pattern must be simple and readily molded.
- (c) *Ease of Cleaning*: The design must be such as to produce a casting which can be easily cleaned and from which the specimen blanks can be readily removed.
- (d) *Metal Economy*: The test coupon should contain the least metal compatible with requirements *a*, *b*, and *c*.

2. The chemical composition of a heat of steel may be well within specified limits, but the steel may not have expected physical properties due to such variables as deoxidization or melting practice, which would make sampling desirable as a check on metal quality. The sample of molten metal is cast in the form of so-called coupon castings, from which specimen blanks are removed. Often several coupons are taken during pouring of the heat to check the uniformity of the metal during that period.

3. It should be emphasized that the properties of the coupon are not

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\*Steel Castings Section, Div. of Physical Metallurgy, Naval Research Laboratory.

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necessarily (and usually are not) the same as those of test pieces randomly removed from castings poured with metal from the same ladle<sup>1</sup>. Gross shrinkage, centerline shrinkage, sand spots, surface defects, etc., as influenced by pouring practice, mold design, molding practice and gating and risering, may occur in various locations with varying degrees of severity. The integrity of the castings themselves must be determined by means other than coupon testing; coupon testing answers only the question of metal quality, not casting quality.

4. Since coupon testing is a criterion of metal quality only, it is desirable, in order to have a consistent standard of comparison, that the design be such that the maximum physical properties of the metal being tested are obtained consistently in the coupon. For example, if the design of the coupon provides only borderline feeding conditions, differences in pouring temperature could result in solid test blanks at one time and porous blanks at another time. Shrinkage of such microscopic nature as to be invisible after deep etching or detectable by radiography may, nonetheless, seriously lower ductility values. Therefore, it would seem desirable that a well-designed test coupon be made standard throughout the steel castings industry. Such a coupon should conform to the requirements stated as *a*, *b*, *c*, and *d* (paragraph 1). Some work has been done in England in an effort to standardize a suitable rosette type of coupon for sampling cast steel<sup>2</sup>.

#### EXPERIMENTAL WORK

5. Six different basic patterns were studied, and steel of the approximate composition, 0.25 per cent carbon, 0.60 per cent manganese, and 0.45 per cent silicon, was used for all tests. The steel was melted in a basic-lined induction furnace and deoxidized with 0.10 per cent of aluminum before pouring.

#### *Pattern Types*

6. Patterns for some of the test coupons used in this investigation are shown in Figs. 1 through 6. Pattern 1 is a conventional type and provides only two tensile blanks. Pattern 2 is a test piece frequently used at the Naval Research Laboratory in experimental work when a large number of tensile specimens are required. This coupon provides 14 tensile blanks, but as many as are required can be added. Pattern 3 is somewhat similar to pattern 2, but has only eight tensile blanks and a comparatively small riser. Pattern 4 is a type often used commercially; two tensile specimens and a bend specimen can be obtained from it. Patterns 5 and 6 are other designs which depend upon a blind riser to feed the blanks. The latter two patterns are designed for easy removal of the blanks from the coupons.

#### *Pouring*

7. In order to minimize variations in properties arising from pouring the

<sup>1</sup> Superior numbers refer to bibliography at the end of this paper.

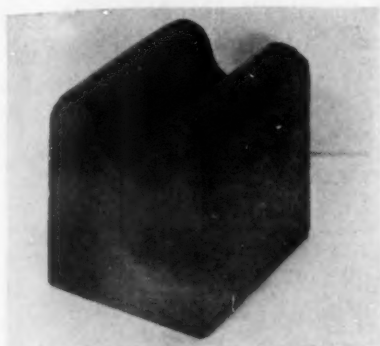


FIG. 1—PATTERN NO. 1—CONVENTIONAL TYPE PROVIDING TWO TENSILE BLANKS.

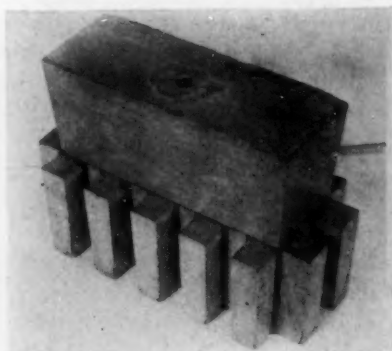


FIG. 2—PATTERN NO. 2—TYPE USED WHEN A LARGE NUMBER OF TENSILE SPECIMENS ARE REQUIRED.



FIG. 3—PATTERN NO. 3—SIMILAR TO PATTERN NO. 2, BUT WITH ONLY EIGHT TENSILE BLANKS AND SMALLER RISER.

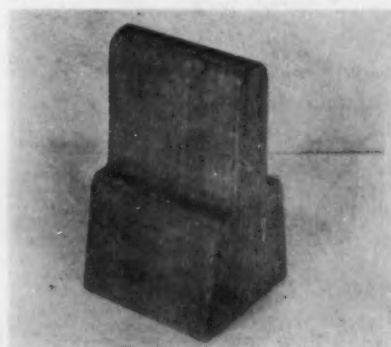


FIG. 4—PATTERN NO. 4—COMMERCIAL TYPE PROVIDING TWO TENSILE SPECIMENS AND A BEND SPECIMEN.



FIG. 5—PATTERN NO. 5—DESIGNED FOR EASE OF REMOVAL OF BLANKS FROM COUPONS. FED BY BLIND RISER.

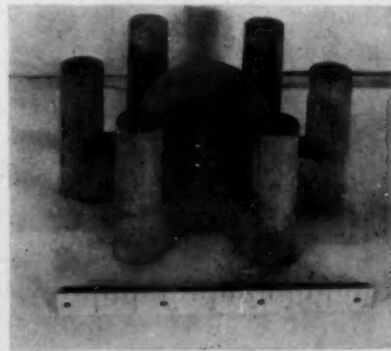


FIG. 6—PATTERN NO. 6—DESIGNED FOR EASE OF REMOVAL OF BLANKS FROM COUPONS. FED BY BLIND RISER.



coupons separately, the six different patterns were molded in one flask and poured through a single downgate with runners leading to the individual cavities. Figure 7 shows the mold incorporating the six test coupons, and Figs. 8 and 9 are cope and drag views of the castings as removed from the mold.

### Heat Treatment

8. Three specimens were sawed from each coupon except from pattern 1, which provided only two specimens. The specimens were normalized from 1700° F. (925° C.) and tempered at 1200° F. (650° C.) followed by air cooling. After heat treatment, standard 0.505-in. diameter shoulder grip tensile test specimens were machined from the blanks.

### Density

9. Density determinations were carried out on machined tensile specimens. After thorough cleaning to remove grease and cutting compound, the specimens were weighed in air and then in water maintained at 20° C. The loss of weight in water, corrected for temperature, gave data for determining the volume of the specimen. The density was then calculated by the equation:

$$\text{Density} = \frac{\text{corrected volume}}{\text{weight in air}}$$

The mean values for the densities of the specimens from each coupon are shown in Table 1, and indicate that patterns 1, 2 and 3 produce specimens of the highest degree of soundness.

### Tensile Tests

10. The tensile tests, summarized in Table 1, confirm the values obtained in the density determinations. Coupons 1, 2 and 3 produce specimens having practically the same yield and tensile strengths, elongation and reduction of area. Specimens from coupons 4, 5 and 6 show yield strengths and tensile strengths approximately the same as those of coupons 1, 2 and 3, but exhibit a marked decrease in elongation and reduction of area, obviously due to the presence of minute centerline shrinkage.

Table 1

PROPERTIES OF TEST SPECIMENS\* FROM PATTERNS NOS. 1 THROUGH 6

Pattern No.	Yield Strength, psi.	Ultimate Tensile Strength, psi.	Elongation, per cent in 2 in.	Reduction of Area, per cent	Density, gm./cc.	Weight of Casting, lb.	Number of Specimens /Casting	Weight of Metal Specimen, lb.
1	48,100	77,100	31.6	47.4	7.819	36.40	2	18.20
2	48,150	77,650	32.7	50.8	7.810	86.0	14	6.1
3	48,050	77,650	32.5	49.6	7.811	48.0	8	6.0
4	49,400	77,500	26.5	36.3	7.801	20.5	3	6.8
5	48,850	77,100	24.0	30.0	7.807	34.0	5	6.8
6	52,300	75,100	18.7	27.2	7.807	23.5	6	3.9

\*Heat No. 203: C—0.25 per cent; Mn—0.71 per cent; Si—0.45 per cent. Normalized at 1700° F. for 1½ hr., air cooled. Tempered at 1200° F. for 2 hr., air cooled.



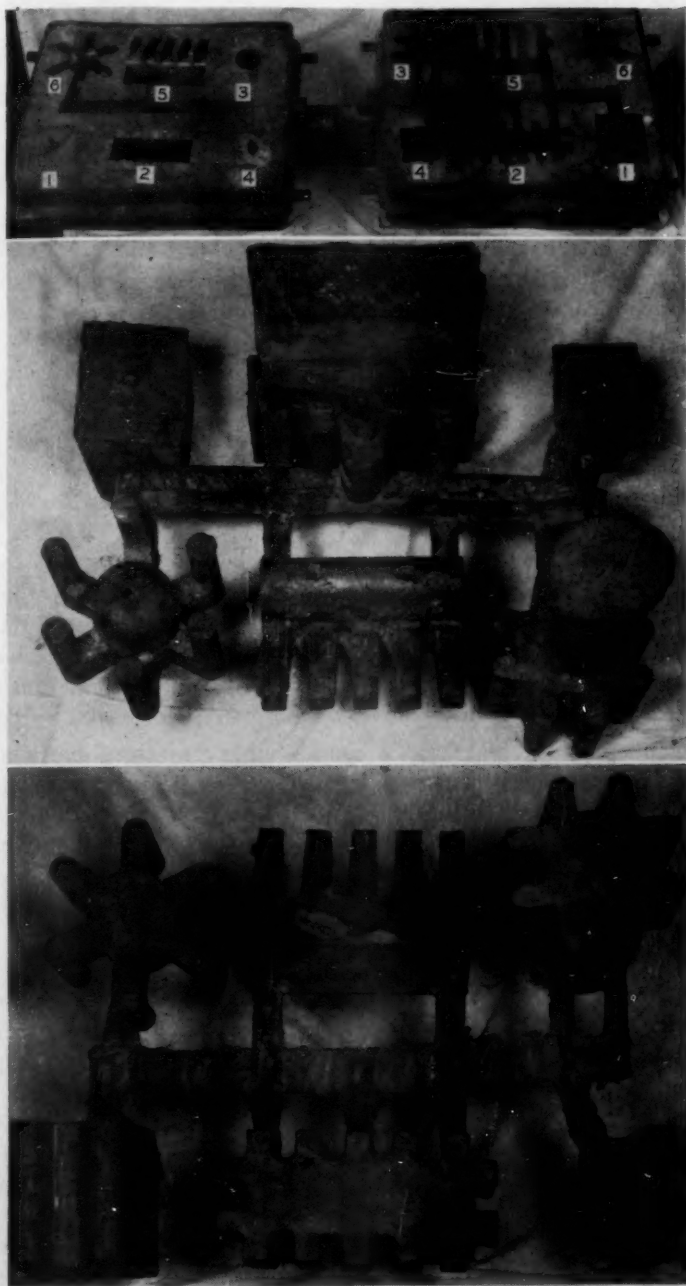


FIG. 7—TOP—COMPOSITE MOLD IN WHICH PATTERNS NOS. 1 TO 6 WERE POURED THROUGH A SINGLE DOWNGATE WITH RUNNERS LEADING TO THE INDIVIDUAL CAVITIES. FIG. 8—CENTER—COPE VIEW OF COMPOSITE CASTINGS AS REMOVED FROM MOLD. FIG. 9—BOTTOM—DRAG VIEW OF COMPOSITE CASTINGS AS REMOVED FROM MOLD.

### *Shrinkage*

11. To show the amount and nature of the shrinkage cavities in the various coupons, the castings were sawed into halves and deep etched with hot, 50 per cent hydrochloric acid after removal of the test specimens. The sectioned coupons are shown in Fig. 10. In all coupons except No. 3, the gross shrinkage cavity was confined to the feed head. However, this is not conclusively significant, since upon close investigation, there is an indication of loose center-line structure in the tensile blanks obtained from the coupons 4, 5 and 6, whereas those obtained from coupons 1, 2 and 3 were apparently sound. The cause of such a condition is quite obvious from an examination of the coupon designs.

12. In coupons 1, 2 and 3, the smallest section (which ultimately becomes the tensile bar) draws its feed metal only a very short distance from the adjoining heavy section, whereas in coupons 4, 5 and 6 the remote portion of the small section must draw its feed metal a distance of approximately 5 in. through a one-inch section with very nearly parallel walls. Therefore, the proximity of the gross shrinkage cavity in and under the riser to the specimen blank is less important than the method of joining the specimen blank to the adjacent heavy section. The shrinkage cavity in coupon 3 extends down into the coupon itself, but is concentrated at the center of the block and does not harm the tensile blanks. While the shrinkage in coupons 4, 5 and 6 is not readily visible in the tensile blanks, the minute centerline shrinkage due to improper conditions of feeding proved detrimental to ductility.

13. Many practical foundrymen consider that the metal head, i.e., the height of the liquid metal above the location where the tensile specimen will be removed, is important to the degree of soundness of the specimen. From previous and present work at the Naval Research Laboratory, the metal head does not appear to be important so long as sufficient metal is available to feed the solidifying specimen.

### *Feeding Methods*

14. Figure 11 shows sketches of two test coupons. One coupon was cast in the conventional manner with the test blanks at the bottom. The other was cast with the test blanks at the top; feeding in this case was accomplished by the use of a blind riser gated into the heavy section at the bottom of the mold cavity. In the first case, both atmospheric pressure and ferrostatic head acted to force liquid metal into the test blank locations, whereas, in the latter case, only the force of atmospheric pressure acted, and even it was diminished by the amount of ferrostatic head<sup>3</sup>. Table 2 gives a comparison between the properties of the specimens cut from these coupons. The close agreement between these results indicates that the pressure head of metal is not the important consideration in determining the soundness of the test specimens.

15. Examination of the sectioned casting from pattern 3 (Fig. 10) indi-

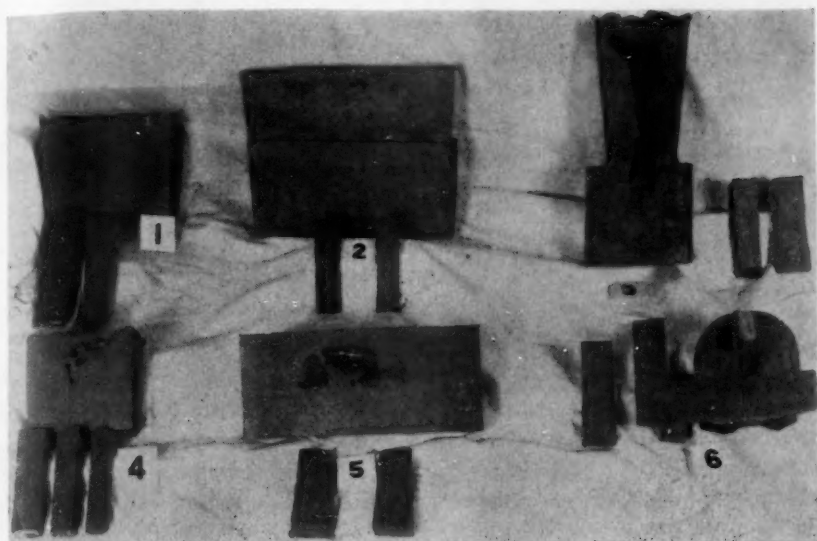


FIG. 10—SECTIONED CASTINGS FROM PATTERNS NOS. 1 TO 6, DEEP-ETCHED (HOT 50 PER CENT HCL) TO SHOW EXTENT AND NATURE OF SHRINKAGE CAVITIES.

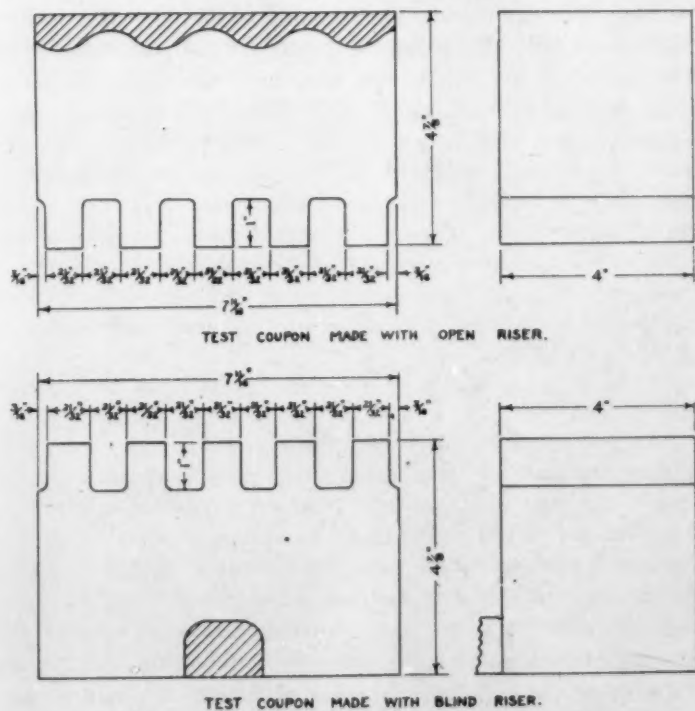


FIG. 11—VIEWS SHOWING TWO METHODS OF FEEDING TEST COUPONS.

Table 2

COMPARISON OF THE PHYSICAL PROPERTIES OF STEEL CASTINGS\*  
FED BY MEANS OF OPEN AND BLIND RISERS<sup>3</sup>

<i>Specimen No.</i>	<i>Type of Riser</i>	<i>Yield Strength, psi.</i>	<i>Tensile Strength, psi.</i>	<i>Elongation, per cent in 1 1/2-in.</i>	<i>Reduction of Area, per cent</i>
A 1	Open	63,800	78,400	30.2	65.4
A 2	Open	63,300	77,000	30.2	66.3
Average	Open	63,550	77,700	30.2	65.9
B 1	Blind	64,000	77,600	30.2	68.0
B 2	Blind	63,200	76,600	32.2	68.0
Average	Blind	63,600	77,100	31.2	68.0

\*C—0.13 per cent; Mn—0.70 per cent; Si—0.95 per cent; Cu—1.69 per cent; S—0.03 per cent; P—0.03 per cent. Specimens dead annealed.

cated that the 6-in. riser of the original design was not needed to produce sound specimens. To verify this observation, four test coupons were cast from one heat of steel. Pattern 3, having a head 6-in. high, as shown in Fig. 3, was used for one casting, the same pattern with a shortened head (3-in. high) was used for the second casting, pattern 7 with the 6-in. head (Fig. 12) was used for the third casting, and pattern 7 with a 3-in. head was used for the fourth casting. The four castings were poured in less than one min. elapsed time, so there was little chance for the composition of the metal to change.

16. The results of the tensile tests after heat treatment are summarized in Table 3, and indicate no significant difference between the properties obtained from coupons with 3- or 6-in. risers. Sections of these castings made from pattern 7 are shown in Fig. 13. Reducing the size of the riser causes the shrinkage-pipe to extend further into the coupon. This is harmless to the tensile blank, as previously pointed out, and reduces the amount of metal required. Of course, sufficient metal must be used to provide adequate feeding of the blanks, but since they are almost completely surrounded by sand, and cool at a relatively rapid rate as compared to the main body of the coupon, a minimum of feed head is required.

#### *Modified Pattern Design*

17. It was found somewhat difficult to remove the sand from the space between adjacent blanks of the castings made from pattern 3. To improve this condition, the pattern design was modified as shown in Fig. 14. This modified pattern design (No. 8) permits the casting to shrink away from the sand more readily, provides more efficient removal of heat from the casting, and lowers the amount of metal required per specimen blank. Tensile specimens from this coupon are free from centerline shrinkage and can be easily sawed (two at a time) or torch cut from the casting (Fig. 15).

18. To confirm the belief that the use of pattern 8 produces specimens which have physical properties equivalent to those from proved designs, coupon

Table 3

COMPARISON OF THE PHYSICAL PROPERTIES OF SPECIMENS\*  
CUT FROM PATTERNS NOS. 3 AND 7 WITH 3-IN. AND 6-IN. RISERS

Pattern No.	Height of Riser, ins.	Yield Strength, psi.	Ultimate Tensile Strength, psi.	Elongation, per cent in 2 in.	Reduction of Area, per cent
3	3	40,850	67,100	34.8	53.9
3	6	41,350	66,750	33.7	52.0
7	3	42,900	66,250	35.7	55.2
7	6	43,250	65,350	35.2	54.9

\*C—0.22 per cent; Mn—0.47 per cent; Si—0.47 per cent. Normalized at 1700° F. for 1½ hr., air cooled. Tempered at 1200° F. for 2 hr., air cooled.

castings from the same heat of steel were poured in molds made with patterns 1 and 8. Blanks cut from these castings were heat treated together, specimens were machined, and tensile tests were made. The results, which are given in Table 4, show that coupon 8, which requires only one-fifth of the weight of metal per specimen of coupon 1, produces steel of the same quality.

19. Table 1 shows the total weight of each of the coupon castings tested and the weight of metal required for each specimen obtained. Coupons 7 and 8, which yield four and eight specimens, respectively, require only 4 lb. of metal per specimen, while pattern 1 requires 18 to 20 lb. and exhibits no

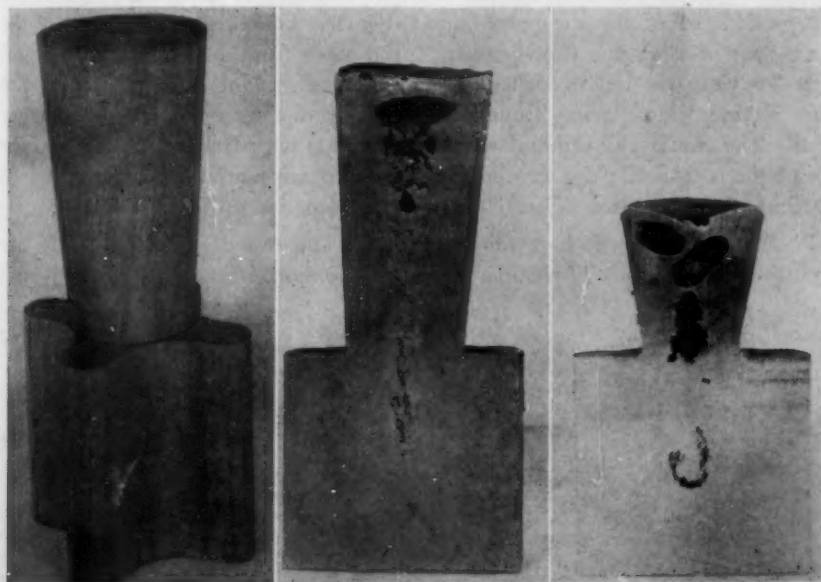


FIG. 12—LEFT—PATTERN NO. 7—USED IN TESTS TO DETERMINE HEIGHT OF RISERS NECESSARY TO PRODUCE SOUND SPECIMENS. FIG. 13—RIGHT—VIEWS OF SECTIONED CASTINGS FROM PATTERN NO. 7 (FIG. 12) SHOWING SHRINKAGE WHEN USING 3-IN. AND 6-IN. RISERS.

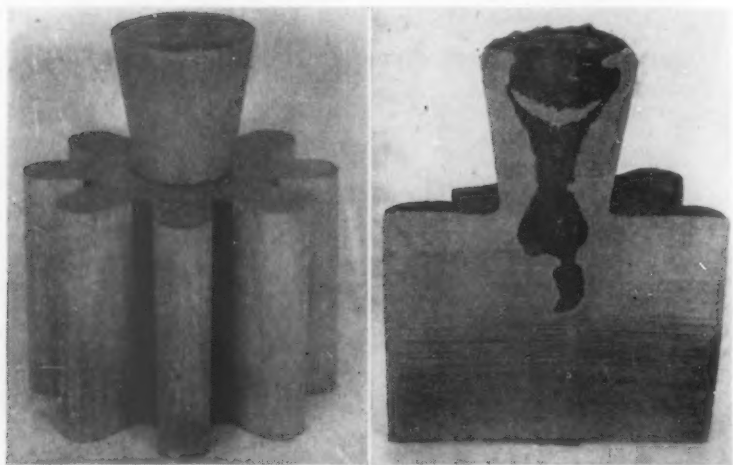


FIG. 14—LEFT—PATTERN NO. 8—MODIFIED DESIGN OF PATTERN NO. 3 TO PERMIT CASTING TO SHRINK AWAY FROM SAND READILY, PROVIDE MORE EFFICIENT REMOVAL OF HEAT FROM CASTING AND LOWER AMOUNT OF METAL REQUIRED PER SPECIMEN BLANK. FIG. 15—RIGHT—PATTERN NO. 8—VIEW OF SECTIONED CASTING.

better properties. Working drawings from coupons 7 and 8 are shown in Figs. 17 to 20.

#### *Effects of Specimen Section Size*

20. To study the effect of the solidification variables caused by changing the section size of the specimen blanks, two test coupons were cast from the same heat of steel, one from pattern 2, the other from a modification of pattern 2 which was redesigned to produce a tensile blank with a 2-in. square cross section. Bars having a one-inch square section were cut from the center of the 2-in. square blanks and were heat treated with the blanks cast in one-inch square sections; this procedure eliminated any variable which might be attributed to the effect of section size upon response to heat treatment.

21. Standard tensile bars were then made and tested. Average results are reported in Table 5. There is a definite indication of reduced strength and

**Table 4**

TENSILE TESTS OF SPECIMENS\* FROM HEAT NO. 205 TO COMPARE  
THE MECHANICAL PROPERTIES OF STEEL OBTAINED FROM  
THE KEEL BLOCK AND PATTERN NO. 8

Pattern No.	Yield Strength, psi.	Ultimate Tensile Strength, psi.	Elongation, per cent in 2 in.	Reduction of Area, per cent	Weight of Casting, lb.	No. of Specimens /Casting	Weight of Metal/ Specimen
1 (keel block)	43,650	72,900	31.5	46.4	40	2	20
8	44,650	73,100	32.2	47.6	32	8	4

\*C—0.23 per cent; Mn—0.58 per cent; Si—0.49 per cent. Normalized at 1700° F. for 1½ hr., air cooled. Tempered at 1200° F. for 2 hr., air cooled.



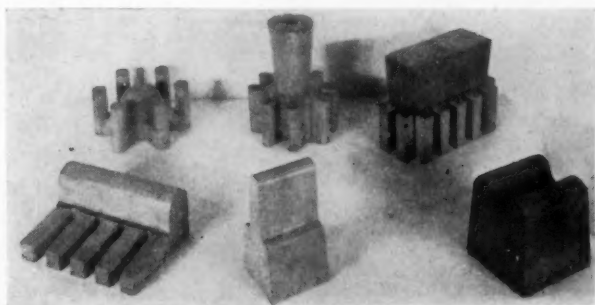


FIG. 16—PHOTOGRAPH OF PATTERNS NOS. 1 TO 6.

ductility in the coupon with the tensile blanks of the 2-in. cross section, due to mass effect. This supports the theory that test bars indicate only the condition of the metal poured and not the properties to be found in the casting.

#### USE OF NECKING CORES

22. To facilitate removal of the specimen blanks from coupon 7, and to eliminate the need for a cold saw or torch, necking cores were placed in the mold at the junction between the specimen blank and the body of the coupon. The details of this arrangement are shown in Fig. 21.

23. Tests were conducted in one case with the opening between the cores

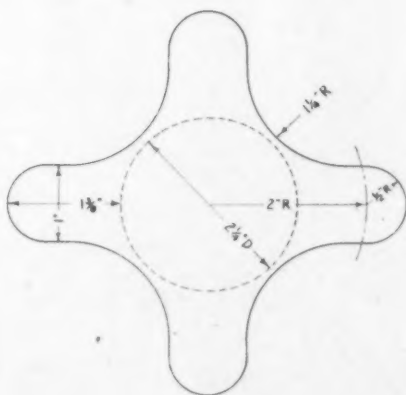
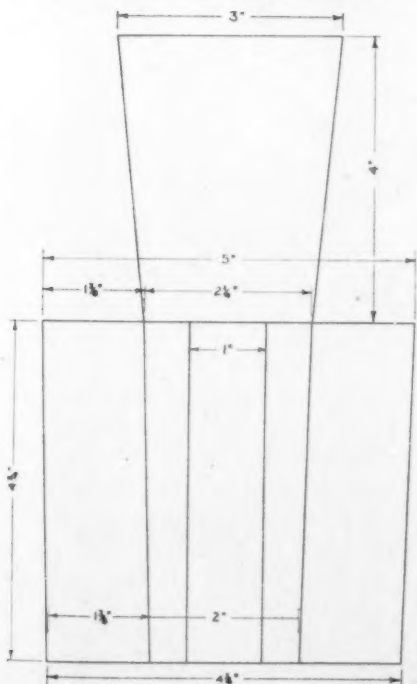


FIG. 17—LEFT—PATTERN NO. 7—VIEW OF FRONT ELEVATION.

FIG. 18—ABOVE—PATTERN NO. 7—PLAN VIEW OF DRAG SECTION.

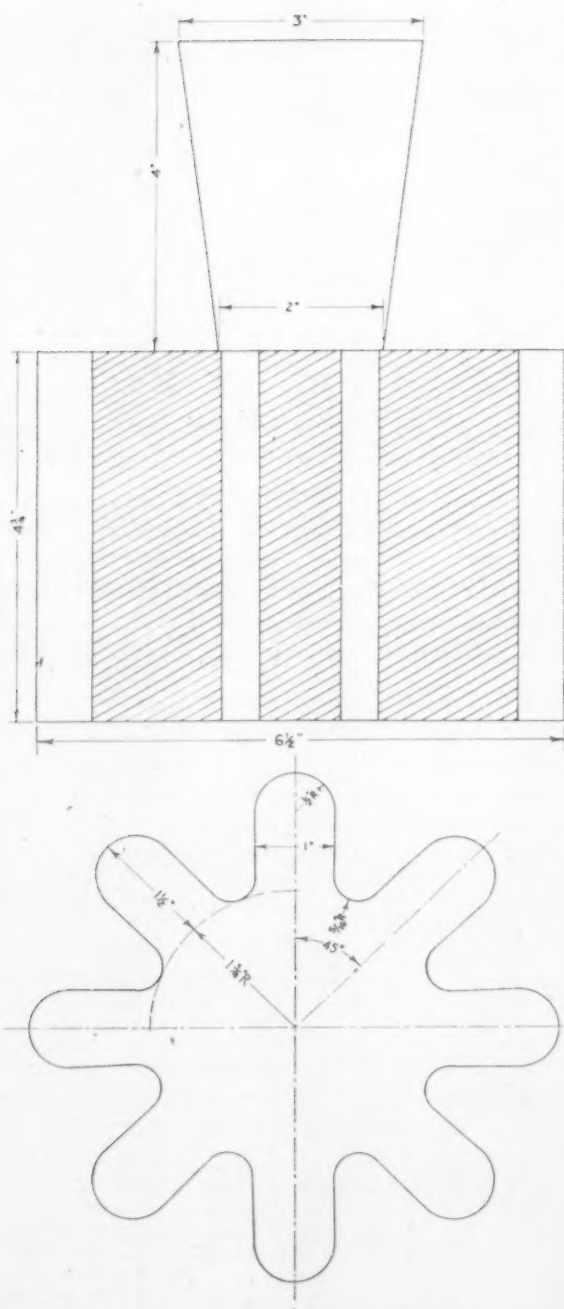


FIG. 19—TOP—PATTERN NO. 8—VIEW OF FRONT ELEVATION. FIG. 20—BOTTOM—PATTERN NO. 8—PLAN VIEW OF DRAG SECTION.

Table 5

COMPARISON OF THE PHYSICAL PROPERTIES OF SPECIMENS\* TAKEN FROM THE CENTER OF BLANKS CAST IN ONE-INCH SQUARE AND 2-IN. SQUARE SECTIONS

Size of Blank, inches	Yield Strength, psi.	Ultimate Tensile Strength, psi.	Elongation, per cent in 2 in.	Reduction of Area, per cent
1x1	58,000	85,000	28.8	49.2
2x2	53,400	83,400	26.5	41.9

\*C—0.29 per cent; Mn—0.73 per cent; Si—0.49 per cent. Normalized at 1700° F. for 1½ hr., air cooled. Tempered at 1200° F. for 2 hr., air cooled.

¼-in., and in another, ⅜-in. In a third mold the cores were omitted to provide control specimens for comparison with those made in molds having the necking cores. All three molds were poured from the same ladle of medium carbon steel. The cores provided the desired necking action, and it was possible to break the blanks from the casting with either the ¼-in. or ⅜-in. neck.

24. Transverse disk specimens were cut from blanks from each of the coupons. These disks were examined radiographically and by deep-acid etching. No evidence of centerline shrinkage was discovered. Three blanks from each coupon were heat treated and machined into shoulder grip tensile test

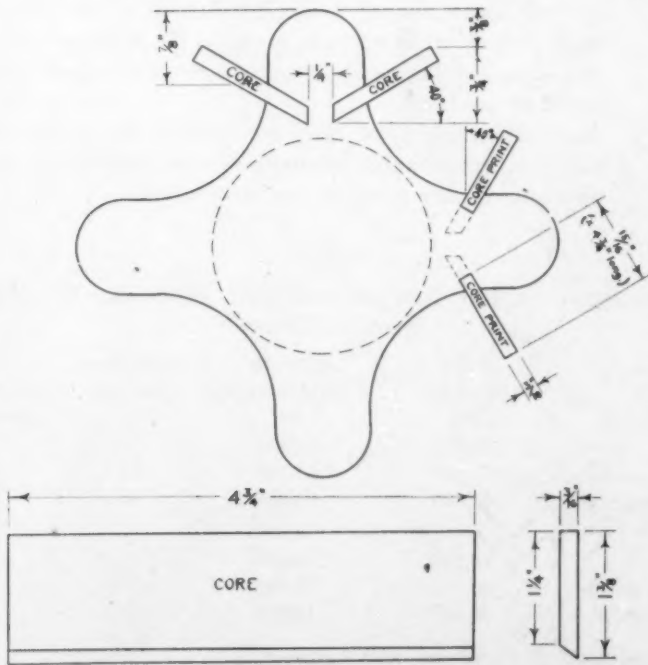


FIG. 21—PATTERN NO. 7—PLAN VIEW OF MOLD (DRAG SECTION) WITH CORES INSERTED.

specimens. The mean values of the tensile tests of the two sets of castings are shown in Table 6.

25. The effect of the necking cores upon the properties is not extremely consistent, but does not seem to be markedly detrimental. The test data from heat 401 indicate that there may be imperfect feeding of the blanks when the necking cores are used. This and the extra labor and care necessary in making the mold with the necking cores counterbalance some of the advantage of easy removal of specimen blanks.

#### CONCLUSIONS

26. The following conclusions can be drawn:

- (a) The cloverleaf type of coupon (7 and 8) provides tensile blanks which are completely sound and which exhibit maximum strength and ductility. This type of coupon requires a minimum amount of metal poured per specimen blank obtained, and the blanks may be readily sawed or torch cut from the coupon.
- (b) Since specimen blanks cut from test coupons do not necessarily reflect the properties of the casting, some standard type of test coupon should be selected and used as an indication of metal quality only.
- (c) Necking cores can be used on coupons of the cloverleaf type, but may cause slightly lowered reduction of area as compared to that obtained in coupons made by the regular method. The specimens can be readily knocked from the coupon rather than sawed or torch cut.
- (d) Since ferrostatic head does not govern the quality of tensile specimen, considerable economy can be achieved by decreasing the ratio of riser metal to specimen blanks.

**Table 6**  
**PROPERTIES OF TEST SPECIMENS POURED WITH AND WITHOUT**  
**NECKING CORES**

	<i>Yield Strength, psi.</i>	<i>Ultimate Tensile Strength, psi.</i>	<i>Elongation, per cent in 2 in.</i>	<i>Reduction of Area, per cent</i>
<i>Heat 401*</i>				
No cores	50,900	81,350	28.3	43.3
3/8-in. neck opening	53,100	81,750	27.0	36.5
1/4-in. neck opening	53,400	81,600	26.8	39.4
<i>Heat 403**</i>				
No cores	46,200 <sub>p</sub>	76,000	31.6	50.0
3/8-in. neck opening	46,150	75,300	32.2	54.3
1/4-in. neck opening	46,100	75,400	33.3	52.1

\*C—0.25 per cent; Mn—0.63 per cent; Si—0.53 per cent.

\*\*C—0.31 per cent; Mn—0.61 per cent; Si—0.57 per cent.

Normalized at 1700° F. for 1 1/2 hr., air cooled. Tempered at 1200° F. for 2 hr., air cooled.

- (e) Since the cloverleaf design of coupon provided blanks for tensile specimens with optimum properties, it could be used to obtain bend test specimens by substituting a section of suitable design for one of the tensile blanks.

### Bibliography

1. Briggs, C. W., and Gezelius, R. A., "The Effect of Mass Upon the Mechanical Properties of Cast Steel," *TRANSACTIONS, A.S.M.*, vol. 26, pp. 367-386, June, 1938.
2. Kain, C. H., and Dowson, E. W., "Design of Test Pieces for Carbon Steel Castings," *PROCEEDINGS, Institute of British Foundrymen*, 1939-'40, vol. 33, pp. 61-65.
3. Taylor, H. F., and Rominski, E. A., "Report on the Use of Blind Heads in the Manufacture of Steel Castings," *TRANSACTIONS, American Foundrymen's Association*, vol. 50, pp. 215-251 (1942).

### DISCUSSION

*Presiding:* T. N. ARMSTRONG, International Nickel Co., Inc., New York, N. Y.

C. E. SIMS<sup>1</sup>: I would like to emphasize what the authors of this paper mentioned, namely, that the test bar should be regarded only as an index to the quality of the steel and not as a criterion of the quality of the castings from a mechanical standpoint. This relationship is in need of clarification because there undoubtedly is considerable confusion among the users of castings, particularly in regard to the importance or the significance of test bar results.

S. W. BRINSON<sup>2</sup>: Why did you use pipe eliminator on some of the open risers and not on others?

MR. WAYNE: We used pipe eliminator on practically all of the risers, but since we were not attempting to make the section immediately under the riser sound it would not matter particularly.

<sup>1</sup>Battelle Memorial Institute, Columbus, Ohio.

<sup>2</sup>Norfolk Navy Yard, Portsmouth, Va.

## Gray Iron—Steel Plus Graphite†

By J. T. MacKENZIE\*, BIRMINGHAM, ALA.

### FORMATION OF GRAPHITE

1. The mechanism of the formation of graphite\*\* has been studied by many metallurgists, but the most concise and clearest statement of it was made by Alfred Boyles after a thorough investigation presented before this Institute in 1937. Boyles summed it up as follows:

(1) Primary austenite freezes out in the form of dendrites, which continue to grow down to the eutectic temperature.

(2) Crystallization of the eutectic liquid begins at centers which grow equally in all directions, forming a cell-like structure.

(3) Segregation takes place in two stages: (a) between the primary dendrites and the liquid, (b) from the crystallization centers of the eutectic outward into the boundaries of the cells.

(4) Constituents formed during the freezing of the eutectic occupy the interstices of the dendrites. The graphite flakes and the phosphide eutectic thus are restricted by the size and distribution of the dendrites.

(5) Graphite flakes do not begin to form until the eutectic begins to freeze. As soon as the eutectic is completely frozen, the flake structure essentially is complete. The flakes grow radially from the crystallization centers of the eutectic outward into the surrounding liquid, resulting in a "rosette" or "whorl" formation.

2. With this clear statement before us, we thought of the method used by Roll to obtain a space model of the graphite flakes. The method is shown in Fig. 1. It consists of firmly establishing the position of the specimen on the stage of the microscope, photographing and repolishing. Between polishings the specimen is measured accurately and when enough plates are obtained they are stacked with the proper spacing between to give the three-dimensional picture as shown. A model can then be constructed of some plastic, as shown in Fig. 2. Roll seemed to think of the graphite only as flakes, but with Boyles' theory in mind we observed the relative position of the flakes and thus obtained the highly satisfactory confirmation of his theory, shown in Fig. 3. Boyles' word "whorl" appears to be a better description than "rosette." Four

†Reprinted from the Twenty-first Annual Henry Marion Howe Memorial Lecture presented at the A.I.M.E. New York meeting, February, 1944, and published in *METALS TECHNOLOGY*, June, 1944.

\*Chief Metallurgist, American Cast Iron Pipe Co.

\*\*"Gray iron," unless qualified, in this paper refers to normal hypoeutectic irons.



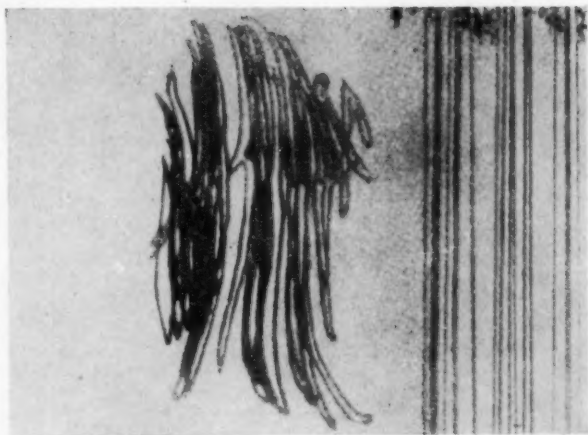


FIG. 1—ROLL'S METHOD OF CONSTRUCTING A SPACE MODEL OF GRAPHITE FLAKES.

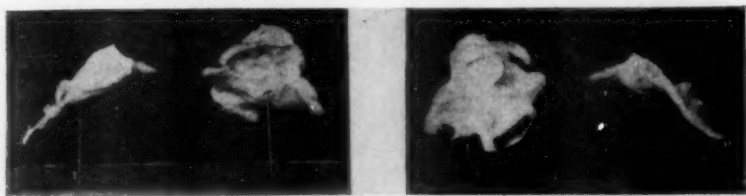


FIG. 2—PLASTIC MODELS OF GRAPHITE FLAKES.

FIG. 3—MODELS OF GRAPHITE WHORLS. ( $\times 150$ .)

more of these formations are shown in Figs. 4 and 5. Three "cuts" are shown as the conventional photographs in Fig. 6.

3. After constructing the individual flakes, we tried setting them up in their actual space relationships, with the results shown in Fig. 7, which gives views from both sides and the top (standard inch included for scale). The magnification of the models is about 150. These are not all of the formations in this volume but enough are developed to show that the space relationships confirm Boyles' reasoning.

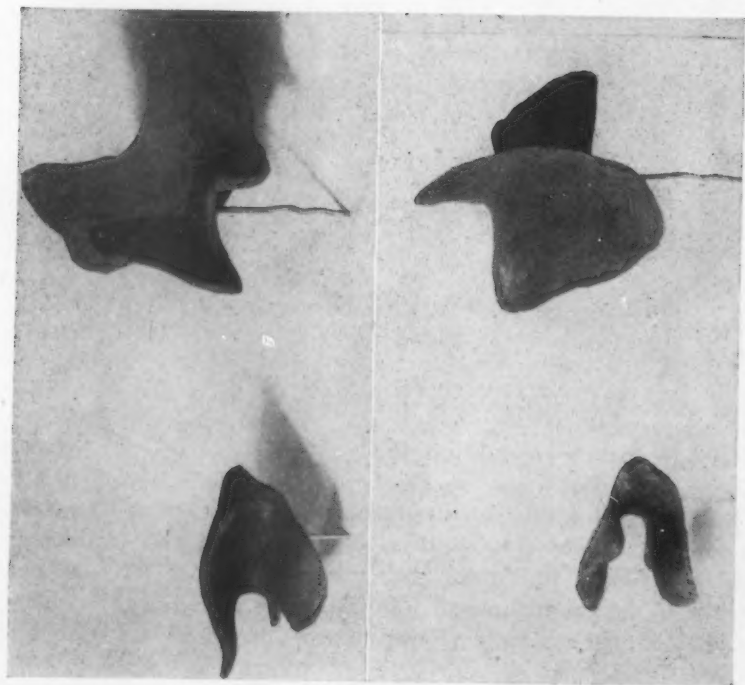


FIG. 4—MODELS OF GRAPHITE WHORLS, SAME FLAKES FROM DIFFERENT ANGLES.  
( $\times 150$ .)

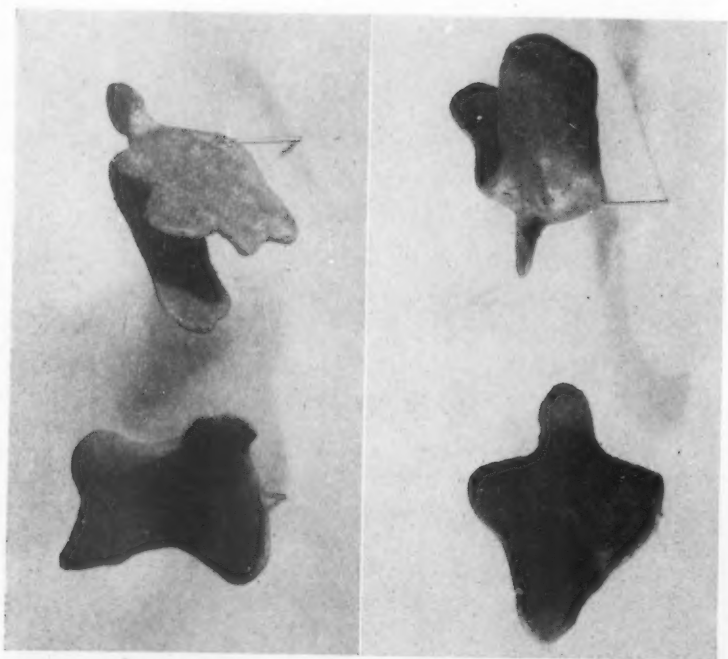


FIG. 5—MODELS OF GRAPHITE WHORLS, SAME FLAKES FROM DIFFERENT ANGLES.  
( $\times 150$ .)

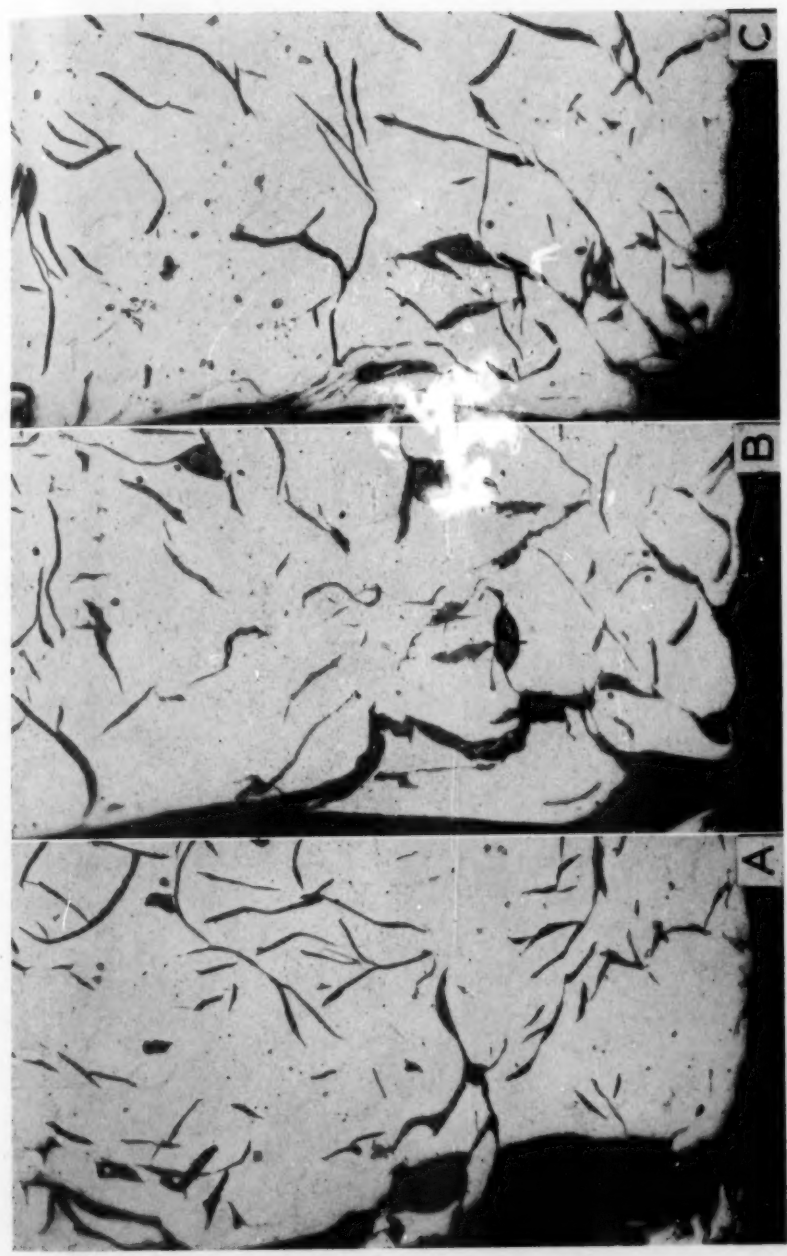


FIG. 6—CUTS OF GRAPHITE-FLAKE MODELS. A—TOP; B—MIDDLE; C—BOTTOM. ( $\times 100$ .)

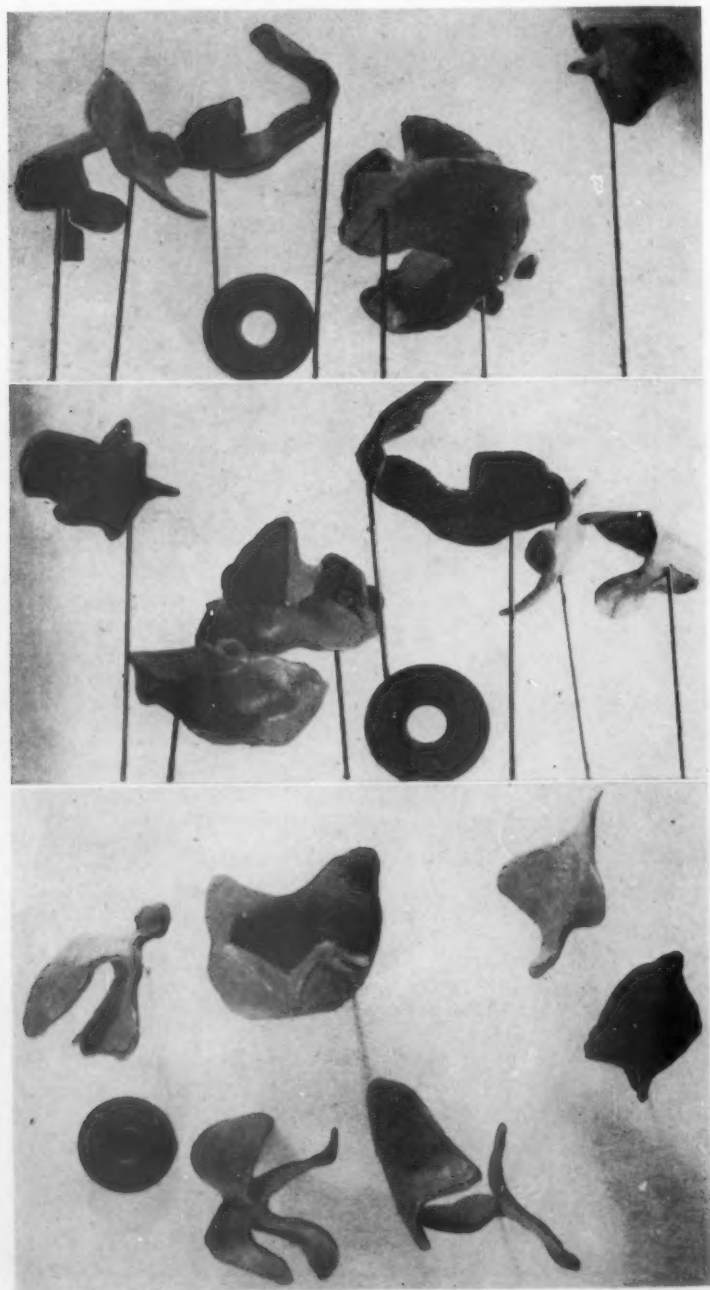


FIG. 7—MODELS OF GRAPHITE FLAKES SET UP IN SPACE RELATIONSHIPS. ( $\times 150$ .)

# The Use of Gypsum Cements in Pattern and Model Making

By E. H. SCHLEEDE\*, CHICAGO, ILL.

## Abstract

*This paper explains some of the characteristics of gypsum cement and how it may be used in making patterns and models. The necessary tools and equipment and five different work methods are described. Figures are used to show some of the characteristics of the material and some of the techniques employed.*

1. When the natural mineral, gypsum, is finely ground and calcined under closely controlled conditions, the product has been commonly known as plaster of paris. This name originated from a rock found near Paris, France. The manufacturing procedures have been improved and formulations worked out to give a series of uniform plaster products which can now be more accurately described as "gypsum cements."

2. In this paper it is proposed to outline how these gypsum cements are correctly used and how they can help the pattern makers and model makers to do certain types of jobs faster, better and more economically.

3. As is true with any material, it must be recognized that there are certain things that must be known and certain basic procedures that must be followed. Only a few basic facts must be known and followed in handling gypsum cements, but unless they are recognized trouble will follow.

4. Skilled craftsmen with a background of pattern, foundry or die work can utilize all of their past experience to take advantage of the possibilities offered by gypsum cements.

5. Anyone applying the methods to be described will have success in gypsum cement pattern making in direct proportion to the skill and knowledge acquired.

## NECESSARY SHOP EQUIPMENT

6. Proper equipment is necessary to make gypsum cement patterns and models, the size and type of work contemplated determining the comparatively inexpensive equipment needed.

### Work Benches

7. The size of the job being made governs the height of the bench. The main body of the work should be in the most convenient position. The

\*Development Engineer, United States Gypsum Co.

NOTE: This paper was presented at a Patternmaking Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 28, 1944.

entire surface of the bench should be flat, and can be of marble, slate, polished plate glass, or treated hardboard. Iron benches can be used, but the rust resulting from moisture must be removed constantly.

8. The benches must have straight edges. The better the work bench, the better and more accurate the work that can be produced.

### *Mixing Bowls*

9. Mixing bowls should be semi-spherical in shape, and made of spun or stamped brass or stainless steel. They should be sufficiently flexible so that they may be sprung to remove set gypsum cement.

### *Tools*

10. The tools used for this type of work are:

- (1) Flat scrapers with one edge smooth and one edge sawtoothed.
- (2) Kidney scrapers, smooth-edged and sawtoothed.
- (3) Spatulas of varying sizes.
- (4) Hand saw, large-toothed and wide set to enable the saw to clear itself.
- (5) Block planes, the size depending on the work.
- (6) Regular carving tools.
- (7) Cutting and filing equipment for making metal templates.
- (8) Angle plates and all other usual devices for pattern making.
- (9) Water facilities nearby for frequent washing of hands.

11. Each type of gypsum cement has a definite consistency which, in terms of the shop, is the lb. of water needed per 100 lb. of plaster to bring the mixture to the proper fluidity for use. It is very important to recognize that water in excess of that required for the normal consistency results in the final pattern being soft and weak. Figure 1 illustrates how the compression strength decreases as the consistency increases. Approximately 18 per cent of the water used for mixing combines chemically with the cement when it is set. Water in excess of 18 per cent (18 lb. of water per 100 lb. of cement) contributes nothing to the final strength or the hardness of the set material. Figure 2 illustrates how the dry density of the material decreases as the amount of mixing water increases.

12. Each type of gypsum cement has its own consistency, and the low consistency (38 to 40) of alpha gypsum gives a pattern which is two to four times as hard and as strong as regular molding plaster, the normal consistency of which is 60 to 62.

13. To take full advantage of the proper consistency and to obtain uniformly satisfactory results, it is recommended that the water be weighed or measured and that the plaster be weighed.

### MIXING

14. In mixing, the gypsum cement should be sifted or strewn into the



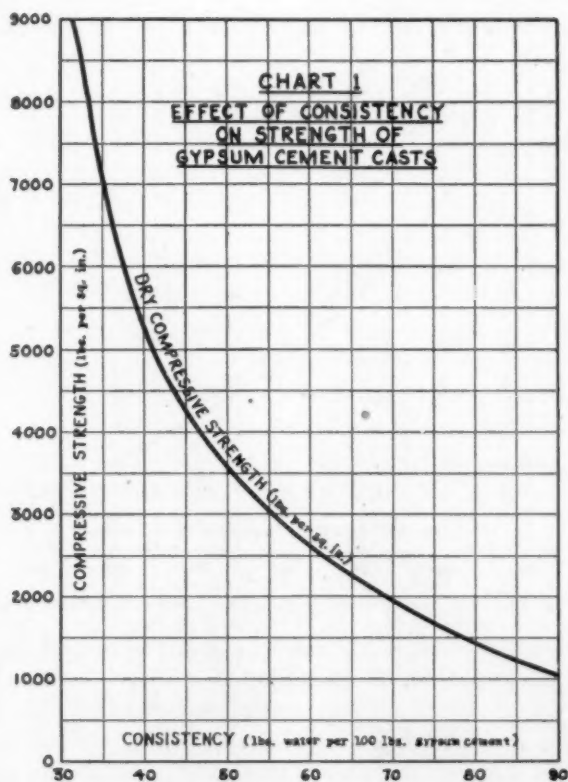


FIG. 1—EFFECT OF CONSISTENCY ON STRENGTH OF GYPSUM CEMENT CASTS.

water. The water should never be poured on the gypsum cement because a poorly mixed, lumpy batch will result. After the gypsum cement has been introduced into the water it should be allowed to soak undisturbed for one to two min., and then thoroughly mixed. A mechanical mixer with an electric clock for accurate timing is recommended for mixing large batches.

15. The mixing vessels should be kept clean. A good mixing bucket for large mixtures and spun brass bowls for small mixtures are recommended. Mixing eliminates the air or bubbles in the mixture and gives a smooth, creamy fluid free of lumps. Improperly mixed gypsum cement will surely give trouble.

16. Contamination of the mixing water and the mixing containers with set material should be avoided, as such contamination will speed the setting of the gypsum cement and change the characteristics necessary in forming the patterns.

#### EXPANSION

17. When gypsum cements set, in most instances, they have a slight

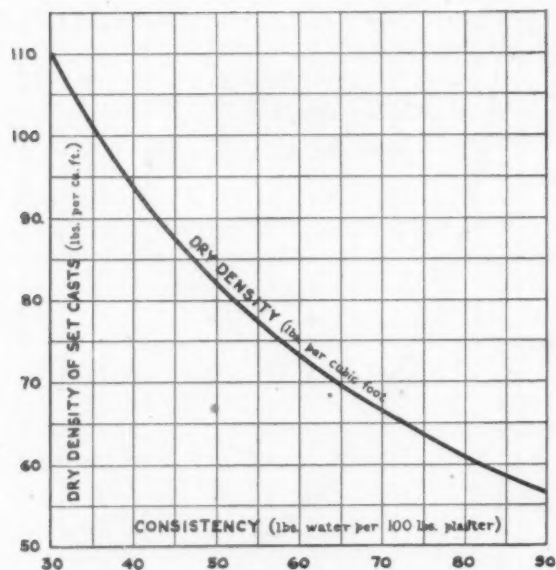


FIG. 2—EFFECT OF CONSISTENCY ON DENSITY OF GYPSUM CEMENT CASTS.

expansion. In recent years, much has been done to control the uniformity and degree of this expansion so that products now are available which have an expansion of 0.02 to 1.25 per cent at normal consistency (Fig. 3). Each of the types shown in Fig. 3 has its specific application in the pattern shop. For example, on a large die where dimensions must be held closely, the gypsum cement with the lowest available expansion is used. To offset the metal shrinkage or to increase the overall dimensions, the material with the highest expansion is used. When constant ratios of gypsum cement to water are used and the mixing procedure is kept uniform, the percentage of expansion can be compensated for and relied upon.

#### UNIQUE CHARACTERISTICS OF GYPSUM CEMENTS

18. Gypsum cements, when mixed with water, form plastic masses which can be molded, shaped or cast.

19. This plastic mass begins first to thicken, then harden, and then set. The thickening or "creaming" stage varies in length of time with different types of cement. To the pattern maker this thickening stage is the most useful, interesting and phenomenal one, and it is accurately described as the "period of plasticity."

20. During this period, the cement can be formed by hand, screeded (or formed) with a template; and reinforced with hemp, sisal, wire mesh, expanded metal, burlap or muslin.

21. The various stages of this period of plasticity should be observed very

closely by the pattern maker because specific results can be achieved only at certain stages. The experienced pattern maker waits until the proper plastic stage is reached before working the gypsum cement.

#### UTILIZING THE PERIOD OF PLASTICITY

22. This valuable period is the one which is most frequently neglected, to the user's disadvantage. It is during this plastic period that the cement should be used to build up patterns and to screed them to shape with templates, because at this time it can be modeled readily, since it has a "controlled" flow. This eliminates the need for molds or "boxing in" which would be necessary if using it in the "free-flowing" state.

23. A little study and experience will quickly show how the progressive plasticity of the cement can be utilized. Different areas of the pattern will require different stages of plasticity because, as this period progresses, the cement gains strength or body and can be built up to the contours required.

24. The length and character of this period of plasticity varies with different types of gypsum cement, so the type should be selected that will meet the requirements of each job.

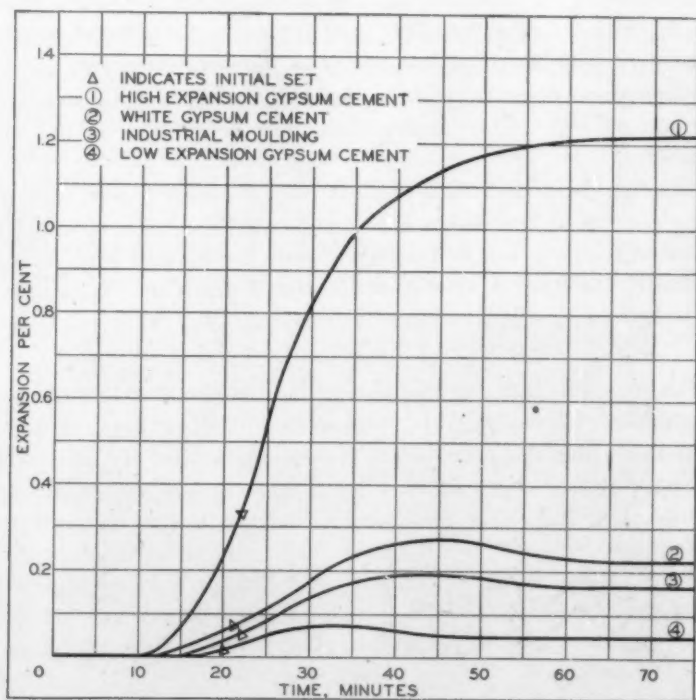


FIG. 3—SETTING EXPANSION OF VARIOUS GYPSUM CEMENTS.

## THE USE AND CONSTRUCTION OF A TEMPLATE

25. A template is a piece of metal which is cut to the shape indicated by the blueprint, and is then used as a tool to screed or form gypsum cement to the desired shape or contour.

26. The thickness of the stock needed for the template depends upon the type of gypsum cement to be used. Steel or any metal strong enough to scrape the "set" cement is necessary. The thickness—or gauge—of the metal is governed by the hardness of the cement. For the hardest types of cement, 16 gauge is practical; for the softest, 27-gauge, half-hard brass is satisfactory.

27. After selecting the correct gauge template stock, the metal sheet is generally first prepared for scribing (or transferring of the design from the blueprint) by coating it with layout dye—a blue coloring matter which makes the scribed lines easier to follow.

28. When a number of steps are required to complete a pattern, and the templates are not required for future references, one template sheet is used, and the successive changes scribed on the template are cut out as the work progresses.

29. However, if it is necessary to keep the templates for future references, a series of templates must be made, one for each successive step. Each of these successive templates must register with the preceding one.

30. When these points have been decided, the scribing is done with the aid of a scratch awl. All reference lines must be scribed on the template for guidance.

31. After all lines have been scribed, the template is cut, and filed to follow the contour of the design accurately. All scratches and imperfections in the finished template will be transferred onto the finished work. Therefore, it is imperative to have a smooth and accurate template. It is now ready to be attached to the sled.

## THE SLED

32. The function of the sled is to support, guide, and steady the template as it is pushed through the plastic mass, screeding it to shape (Fig. 4).

33. In using the sled, the bench is greased so that the sled will slide easily. Care must be taken so that there is no grease under the molding being made. The sled consists basically of a "slipper-board," a board to which the template is nailed or bradded, a guide board and an outrigger board.

34. The template board is cut out to a contour roughly similar to the contour of the template. Clearance is provided so that the wood does not project beyond the template, which would result in ruining the shape being formed.

35. The sled construction is modified as required by the type of work involved.

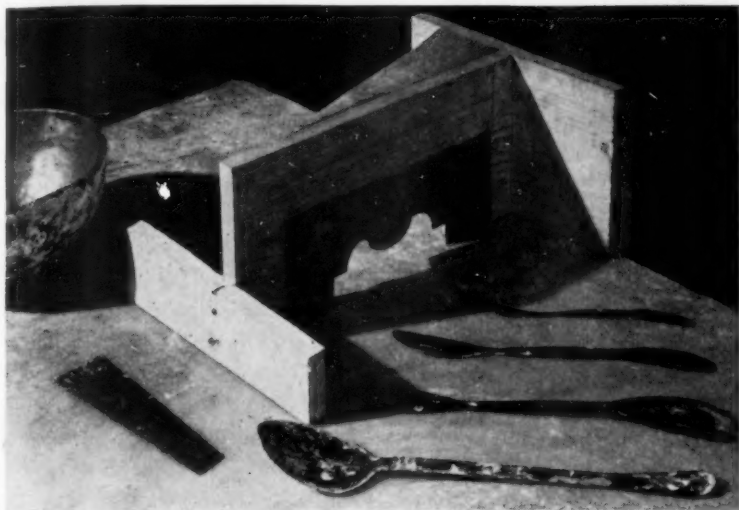


FIG. 4—SLED FOR STRAIGHT RUN WORK WITH TEMPLATE BRADDEN IN PLACE. THE TOOLS ARE—BRASS MIXING BOWL, SAW EDGE SCRAPER, FLATTENED MIXING SPOON AND THREE SIZES OF SPATULA.

#### METHODS OF MAKING PATTERNS

36. In forming gypsum cement patterns there are five principal methods. One or more of these methods are used to produce the desired pattern.

##### (1) *Straight Run Molding*

37. Straight run molding work is made by the use of a template fastened to a sled which is pushed through the plastic mass (Fig. 4). A first run or follow-board is formed, and this serves as a support for the pattern (Fig. 5). The follow-board template is cut to follow the contour of the back of the pattern, and the cement is mixed at slightly below normal consistency.

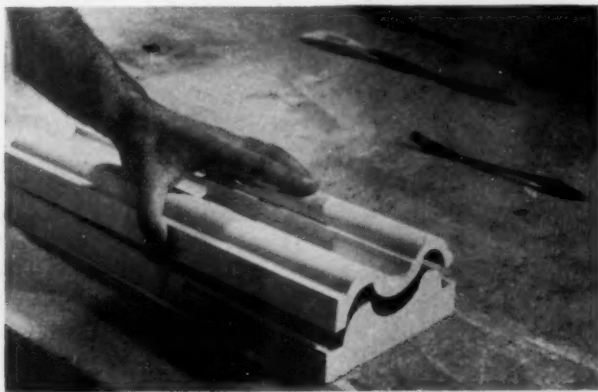


FIG. 5—THE COMPLETED PATTERN IS SEPARATED FROM THE FOLLOW-BOARD BELOW. AFTER SHELLACKING, IT IS READY FOR USE.

38. As the "creaming" action progresses, the cement becomes stiffer, and therefore easier to control with a spatula.

39. The template is now pushed firmly through the plastic mass in one direction only. When it has been pushed through the mass once, the sled is picked up, the template cleaned, and the waste cement discarded. Additional cement is added to the mold to fill in the remaining voids. The sled is returned to its starting position and again pushed through, the operation being repeated as often as is necessary.

40. The high spots in any profile are the most difficult to build up and require the particular attention of the craftsman. The low spots practically take care of themselves.

41. When the first mixture has progressed so far through the period of plasticity that it will no longer make a good bond, the work with that mixture should be stopped. Gypsum cement should not be retempered, as it will become chalky and will have no strength. The less the cement is handled during forming, the better. When a large mass of cement is used, it is not advisable to bring the cement directly up to the template with the first mixture, because of expansion difficulties.

42. A second mixture should be made for continued building, filling the remaining voids and screeding as before. If the work is not completed with the second mixture, a third or even a fourth mixture may be used. However, these additional mixtures should be made at normal consistency. That is, they should be more fluid than the first mixture, which was made below normal consistency.

43. If, when applying these subsequent mixtures, the new material crumbles or tears, a greater amount of the mixture should be applied and screeded as quickly as possible. This crumbling or tearing is due to the absorption of water by the first mixture, which has set, from the subsequent mixtures. However, care should be exercised not to apply so much of the new mixture that the entire mold will become water-soaked.

44. When the follow-board—or support—has been completed, it is shellacked or otherwise sealed. Parting compound is then applied over the shellac. Meanwhile, the template is changed to the "face" contour by cutting and filing.

45. A new mixture of gypsum cement is applied over the follow-board, and the screeding continues, using the same procedure as in making the follow-board. When this is finished, the pattern can be cut to length, carved, mitred, or further fabricated in any desired manner. After a final shellacking it is a completed pattern.

## *(2) Square, Rectangular or Oblique Shapes*

46. The technique is the same as that used in running straight work. The only difference is in the use of a slab which conforms to the basic shape



of the pattern (square, rectangular, hexagonal, etc.), only larger, so as to provide a surface for the sled to ride on (Fig. 6). The slab is pivoted around a center stud attached to the bench. This pivot permits the job to be swung into a position convenient to the craftsman.

### (3) Circular Shapes

47. Circular shapes, such as wheels, disks and housings, are made with a modified arrangement of the run-work sled. The template is rotated around a center post to produce a symmetrical pattern (Fig. 7).

48. For these circular shapes, the template is made with the center line scribed. A pivot plate is centered to this line and nailed or screwed in place on the template board.

49. A center post is placed in a hole in the bench. This post should have a running thread, with a double nut for height adjustment. The pivot point at the top must be absolutely rigid and should be set higher than the top of the pattern to be made, so that the template will clear the pattern. By rotating the template around the center post, sweeps of any diameter, or segments, can be produced.

50. The mixing and handling of the gypsum cement in making a turning should follow the same procedure as explained for run work. For thin sections, a follow-board must be made first, and the pattern built on it. The



FIG. 6—SQUARE SHELL PATTERN BEING REMOVED FROM THE FOLLOW-BOARD. NOTE SLAB IS LARGER THAN PATTERN BUT OF SAME SHAPE.



FIG. 7—SEPARATING A CIRCULAR SHAPE PATTERN AFTER THE FINAL TURNING HAS SET.

accuracy of the finished work depends upon the accuracy of the equipment used. However, accuracies within 0.005 in. can be maintained by this method.

#### (4) *Cylindrical or Kindred Shapes*

51. By this method the cement is formed onto a rod which is rotated horizontally in journals in a box. As it is rotated, the excess cement is screeded by a stationary template attached to the box. The work, rather than the template, is rotated in this method (Fig. 8). The journals in the box must fit the size of rod to be used. A handle for turning, such as a lathe-dog, is clamped to the rod.

52. The template is made in the usual manner. However, the true center on the template must be cut away to allow for the radius of the rod. Therefore, an arbitrary line must be established on the template in order to locate it on the template board in its true position. The template board is fastened securely to the furring strips on the inside of the box, which will support the template board at the centerline height.

53. The pattern is built up on the rod in the following manner: twine is tied to the rod at the opening of the template, the rod is then rotated and the twine guided and wound around the rod in the manner of a screw thread, from one end to the other and back to the starting point, where it is securely fastened. This twine forms a bond between the rod and the cement.

54. A piece of metal may be tied crosswise to the rod at this time, if necessary, which will help support the cement as it is applied. If the rod is not to be used again, i.e., if it is to be left in the pattern, the piece of metal may be soldered to the rod.

55. A small batch of cement, mixed at "below normal consistency," is now spread along the entire length of the pattern. The rod is rotated slowly and, as the cement "creams," more is added. Care should be taken not to apply too much of the mixture at one time, as too great a quantity will, of its own weight, cause the cement to sag away from the rod. Sagging will break the bond between the cement and the rod and, consequently, the pattern cannot be rotated, and it will be necessary to start over again. All that should be accomplished with the application of this first mixture is to secure a firm foundation for the subsequent mixtures.

56. All "glazed" surfaces must be "roughened" before proceeding with the application of new mixtures. As the pattern is rotated, the waste material that is screeded by the stationary template must be constantly removed and discarded. Only a clean template will produce satisfactory work.

57. All of the additional mixtures required should be of normal consistency and the number of mixtures needed depends upon the difficulty in building up the contours of the particular work. In applying the additional mixtures, care should be taken that large masses of the cement do not come in contact with the template. A small clearance must be provided to allow for the "setting" expansion of this large mass. Failure to allow for this "setting" expansion will result in "chattering" as the pattern is rotated. The final small clearance is then filled with a finishing coat of a fresh mixture spread over the entire pattern.



FIG. 8—FINISHED CYLINDRICAL SHAPE BEING REMOVED FROM THE BOX. THE ROD IS REMOVED FROM THE PATTERN BY TWISTING AND PULLING.

*(5) Built-up Work*

58. In built-up work, gypsum cement slabs are used in a manner similar to that in which boards are used in wood work (Fig. 9). Slabs can be cast by spreading the gypsum cement on the surface of the work bench. As the cement creams, it is built up to the thickness desired. If both faces are to be parallel, the center should be built up slightly higher than the thickness blocks placed at the endges. A piece of glass is then pressed down until it rests on the blocks, squeezing the excess cement out at the sides. These slabs can be made to any thickness and contour. Also, they can be reinforced with any convenient reinforcing material to give them added strength.

59. When "lofting templates" are used, as in aircraft or similar work, the templates are set up in their specified positions. The gaps or spaces between the templates may be spanned by the use of reinforcing slabs or expanded metal. The slabs may crack in bending, but the cracks will bind when a new cement mixture is added.

60. The cement is put on free-hand in the shape of the lofting templates. This free-hand shaping is done mostly while the cement is still in its plastic state. After the cement has set, it may be carved, scraped, or additional cement can be applied. Gypsum cement should never be carved unless it is moist. If the cement is dry, it will chip ahead of the carving tool, thus making it impossible to produce a smooth cut.



FIG. 9—BUILT-UP PATTERN. THE FINAL FINISH IS PRODUCED BY PLANING, CARVING AND SANDPAPERING.

## REINFORCEMENTS

61. Long-fibered hemp is the most satisfactory, versatile and universally used reinforcement. The hemp is matted in baling, so it must be picked apart to loosen the individual strands. Then a handful is made into a flat bat and dipped into the cement mixture. This bat then can be added to the undercoating of cement being screeded, thus becoming an integral part of the pattern. The number of bats needed depends on the size of the job. Handfuls of the hemp may be dipped into the cement mixture and formed into a rope to tie metal or wood reinforcements in place.

62. Thin, flexible slabs may be made by spreading the hemp on the bench and applying a thin layer of gypsum cement over it, pressing the cement firmly into the fibre while spreading. After the cement sets, it can be cut easily into slabs of a convenient size. Uncarded hemp or sisal fibre can be obtained in large quantities from wholesale distributors; in smaller quantities, from local upholsterers' supply houses.

63. Other reinforcements are wire mesh, expanded metal, metal rods and flax fibre for delicate work. Wire can be used as a reinforcement, but it must be wrapped with dipped hemp or flax fibre, which will furnish a mechanical bond between the wire and the cement.

64. To avoid distortion, metal rods and wooden bar reinforcements which are to be used as supports for the finished pattern when handling, should always be tied onto the work with hemp fibre after the setting expansion has taken place.

## Appendix

## GYPSUM CEMENTS—WHAT THEY ARE—HOW THEY ARE MADE, AND THEIR CHIEF PHYSICAL DIFFERENCES

Gypsum cements are made from the mineral-gypsum rock; which is either white or gray in color, according to its purity (some formulations are gray due to additives).

The rock is finely ground and calcined in an open kettle, being agitated constantly during the process. Calcination drives off three-quarters of the chemically combined water, changing the composition from  $(\text{Ca SO}_4 \cdot 2 \text{ H}_2\text{O})$  to  $(\text{Ca SO}_4 \cdot \frac{1}{2} \text{ H}_2\text{O})$ .

Regular calcined gypsum cement has a normal consistency of 80 to 85 lb. of water to 100 lb. of cement, and has a compressive strength of 1600 psi. If calcium chloride ( $\text{CaCl}_2$ ) is added to regular calcined gypsum cement in controlled amounts, the water content of the cement can be reduced to 60-65 lb. per 100 lb. of cement and its compressive strength is raised to 2500 psi.

This method assures uniform products, but high compression strength materials are not possible.

The type of gypsum cement used as a base for cements used for patternmaking purposes is made from the purest rock obtainable. It is not calcined in an open vessel and agitated during calcination, but is calcined in a pressure vessel without agitation. The gypsum crystals produced by this method are sharp and angular as compared to the rounded crystals produced by "kettle" calcination. The normal water content drops to 40 lb. per 100 lb. of cement, and the compressive strength rises to 4000 psi.

By using this material as a base, formulations having a dry compressive strength of 15,000 psi. can be produced.

It is evident from the foregoing that, as the water requirement decreases, the dry compressive strength increases. In using gypsum cements, it is all-important that the water content of a mixture be kept to the minimum required to produce a cement of the proper working qualities.

## DISCUSSION

*Presiding:* VAUGHAN REID, City Pattern Foundry & Machine Co., Detroit, Mich.

*Co-Chairman:* F. C. CECI, Cleveland Trade School, Cleveland, Ohio.

L. L. WERNER<sup>1</sup>: What is the best procedure and how long would you let the plaster dry before you put shellac on it?

MR. SCHLEED: As soon as the gypsum cement is set you can shellac it. The mistake so many people make in shellacking gypsum cement patterns is that they have the shellac too thick. When you put a coat of shellac on a gypsum cement pattern the shellac should be cut back thin enough so that the first coat will be absorbed by the gypsum cement. Put several coats on. You do not have to wait. Most of these patterns shown are made over a period of not more than 6 hr.

MR. WERNER: We have experienced trouble with the shellac peeling off.

MR. SCHLEED: You are putting it on too thick.

MR. WERNER: I thought that it was because we were putting it on when the plaster was too wet.

MR. SCHLEED: If the plaster is too wet the shellac will curdle when it contacts the gypsum cement. Always work the gypsum cement as dry as possible, because if it is water soaked it is no longer possible to make a bond. You will be unable to bring up any fine corners. You must rely on the capillary attraction of the set gypsum cement to hold to the fresh gypsum cement that you are putting on.

G. F. SMITKA<sup>2</sup>: What material do you use to separate the pattern from the follow board?

MR. SCHLEED: There are a great number of things that can be used. The one that is most commonly used is stearic acid and kerosene with one per cent of aerosol. Another common separating medium is petroleum jelly with kerosene. Lard oil and light machine oil are used. In the finest work, spirits of camphor is employed. The separating medium should be carefully applied, as too heavy an application will cause wrinkles or "separator runs" which will be visible in the completed job. When a gypsum cement sets it gives off heat. An exothermic reaction takes place. That will cause the work to sweat loose from the surface upon which it sets. If the work is set up on plate glass there will be no bond. But on any other material a thin film of a separating medium should be used.

In the pottery industry they use potter's soap or light potash soap, working up a foam to coat the entire work. The use of soap with patterns is not advised because it will not build up a sufficiently thick film and is a water soluble material.

MR. SMITKA: I have used plain lard where the body of the plaster was heavy enough. There would be enough heat there to soften the lard and it worked out nicely.

MR. SCHLEED: You will not get an accurate reproduction.

<sup>1</sup> Crouse Hinds Co., Syracuse, N. Y.

<sup>2</sup> Ampco Metal, Inc., Milwaukee, Wisc.



MR. SMITKA: It all depends upon how the lard is applied. The object is to apply it so that you do not find any lines.

MR. SCHLEEDE: That is correct. All that is needed is a thin film of a separating medium that will not wash.

MR. SMITKA: The lard is heated before applying and hardens on the work. Later, the heat from the plaster will soften it.

MR. SCHLEEDE: If too much separating medium is used it will be absorbed by the plaster and result in a soft surface.

MEMBER: In a plaster pattern reinforced by wood (Fig. 7), how do you prevent distortion and warping because of the absorption of water by the wood?

MR. SCHLEEDE: The use of wood should be avoided as far as possible because the moisture will cause the wood to swell and distort the plaster.

MEMBER: What happens to the gypsum cement when it is dried in the oven?

MR. SCHLEEDE: Air drying is best for plaster patterns, but it is not necessary to wait for them to dry if they are sealed with shellac. As soon as the shellac is dry the patterns can be used in the foundry.

MEMBER: Is there any relation between these plaster patterns and the investment molding process?

MR. SCHLEEDE: That is a different process entirely and must not be confused with plaster patterns. The plaster used in the molding process has an aggregate added and must be completely dehydrated before the metal is poured into the mold.

CO-CHAIRMAN CECI: In connection with these emulsions that are used on plaster, the pattern supply houses today have pattern materials that are very thin and are admirably adapted to that work. They will help to prevent lump formation and streaking.

MR. SCHLEEDE: A word of caution about the use of shellac. Do not use anything besides alcohol to cut the shellac. Do not use oxalic acid because that will result in separating trouble.

W. K. VOSS<sup>3</sup>: How long does it take the gypsum cement to set and how long can it be worked while it is in the plastic state?

MR. SCHLEEDE: That depends upon the type of gypsum cement selected for the job. The dentist wants a quick-setting material and that is the mistake that a great many patternmakers make. The normal set of gypsum cement, according to the working period, is from 25 to 30 min., whereas dental plaster sets in 10 to 12 min. You must select the material that will work the best for you. You do not have to finish the job by the time the first batch is set. You can work on it all day or for two days. The aircraft industry might work on a job for a week. The job does not have to be finished with one mixture of plaster.

<sup>3</sup> Blackhawk Foundry, Davenport, Iowa.

## Drying and Preheating of Foundry Ladles

By C. E. BALES\* AND F. MCCARTHY\*\*, IRONTON, OHIO

ALL iron and steel foundrymen agree that ladles of all sizes should be dried thoroughly before being used, yet in many foundries this important operation is neglected, or it is handled in a superficial manner. The term "drying" is really a misnomer, because what actually is required is a thorough baking or preheating of the ladle lining. This is essential to secure the best service from the lining and the greatest number of salable castings.

In obtaining data for this paper, personal visits were made to many foundries to observe the various methods of heating ladle linings. In addition a questionnaire was directed to approximately 2000 foundries in the United States and Canada, to obtain from them a record of their experiences with "green" linings. It was found that the use of incompletely dried linings invariably caused boiling in the ladle and that this action was detrimental to the iron and steel.

### Effect of Boiling

Boiling in newly lined ladles was found to cause inverse chill, increased depth of chill and hard spots in the castings. It causes blow holes, misruns, cold shuts, and dirty, weak iron of poor structure.

It also causes minute gas inclusions in the castings, particularly in the cope section, which usually are not discovered until the castings are being machined.

Damp ladle linings are exceedingly dangerous, since the boiling iron or steel may spill over the side of the ladle and cause severe burns to workmen. In some cases, explosions have occurred and, in one instance, 300 lb. of iron was thrown as high as the foundry ceiling. In another instance, the entire ladle lining was blown out.

In ladles handling steel, the boiling undoubtedly brings about some pick-up of hydrogen and causes porosity in the castings. In one foundry, some sand containing calcium chloride was used in the ladle linings and while the linings were apparently dry, the boiling was so severe that the entire heat had to be "pigged."

### Behavior of Damp Linings

Some foundries have experienced so much trouble in trying to remove all the water from newly lined ladles that they have given up hope and simply "pig" the first iron or steel. Such practice is an economic waste of manpower and fuel and should

\*Vice President, The Ironton Fire Brick Co.

\*\*Deceased.

NOTE: This paper was presented at a Refractory Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 25, 1944.

not be tolerated if suitable drying equipment is available.

It generally is recognized that damp ladle linings cut out much faster than those which have been dried thoroughly and preheated. The damp linings spall and crack, the cracks open on succeeding heats and contribute to unexpected run-outs. Such linings seem to cause more trouble from slagging.

### Ladle Lining Materials

Many different types of refractory materials are used for ladle linings, and the method and degree of drying depends upon the character of these materials. In iron foundries, the following materials commonly are used:

- (1) Fire clay, silica sand and molding sand.
- (2) Fire clay, ground fire brick and silica sand.
- (3) Fire clay and silica sand.
- (4) Regular fire brick or splits, for bottom and sides.
- (5) Fire clay and ganister.
- (6) Ladle bottom tile, with fire brick or mud lining.
- (7) Siliceous ramming refractory.
- (8) Super-quality refractory bonding mortar.

In steel foundries the following materials are used:

- (1) Fire clay and ganister.
- (2) Fire brick.
- (3) Siliceous ramming refractory.
- (4) Siliceous ramming refractory with ganister.

Some foundries use silicate of soda in their ladle lining mixtures to develop a hard structure, but the authors feel that this is poor practice. The sodium silicate migrates to the lining surface, fuses when heat is applied, and causes slagging.

Furthermore, the hardened surface prevents the escape of the moisture, and it is exceedingly difficult to dry such linings.

High grade fire clay consists essentially of the mineral kaolinite which contains 14 per cent chemically combined water. The fire clays ordinarily used in foundry practice contain some kaolinite, but they also carry quite a bit of silica, as well as some carbon and small amounts of iron and lime bearing minerals, such as pyrite, siderite, and gypsum.

The chemically combined water content of foundry clays runs from 6 to 12 per cent and, while it is possible to drive out most of this water at 930° F., the final traces may not be eliminated until a temperature of 1450° F. is reached. The loss of this water of crystallization is a function of both time and temperature and, considering the insulating power or low temperature gradient of the refractory lining, time is a very important factor.

It requires a temperature of 1650° F. to burn out all the carbon and to dissociate the siderite into iron oxide and carbon dioxide, and the pyrite into iron oxide and sulfur dioxide. A temperature of 2400° F. is required to dissociate the gypsum into lime and sulfur trioxide.

Fortunately, foundry fire clays contain very small amounts of carbon and these iron and lime minerals. However, it is essential that they be broken up by heat or they will damage the iron or steel by boiling and by sulfur absorption.

### Importance of Preheating Ladles

The authors would like to stress the importance of both thorough drying and adequate preheating of the ladle linings. In many gray iron

foundries, the metal is tapped at 2800° F. into ladles that have been preheated scarcely to 1600° F.

In many steel foundries which employ electric melting, the steel is tapped at 3000° F. or higher, into ladles that have been preheated to about 2400° F. The authors believe that it would be much better to preheat the ladles to a temperature close to that of the metal to be received.

Ladles also should be preheated for a sufficient period of time to satisfy the heat capacity of the ladle refractories. The time required depends upon the type of refractory materials used, thickness of the lining, type of burner equipment, combustion conditions and the lining temperature desired.

Some ladles have been observed where the surface of the lining had been preheated to a bright red heat, yet the metal boiled considerably when poured into them. This was due to a short preheat time which left half the thickness of the lining still damp.

#### Vent Holes in Ladles

In a steel foundry using electric melting, studies on a 3-ton ladle with a 4-in. lining of siliceous ramming refractory showed a face temperature of 2500° F. while the temperature of the ladle shell was 480° F. This emphasizes the insulating properties of ladle refractories and shows the necessity of taking sufficient time to do a thorough job of preheating.

The authors regret that they are unable to recommend proper lining thicknesses and the time actually required for drying and preheating ladles of various sizes.

#### Methods for Drying Ladles

To thoroughly dry ladles of all sizes and to reduce the time of drying, it is recommended that the ladle shells be perforated with vent holes of  $\frac{1}{8}$  to  $\frac{1}{4}$ -in. diameter. These holes could be placed on 1-in. centers for hand and bull ladles, on 2-in. centers for ladles up to 1,000 lb., and on 3-in. centers for larger ladles. These vent holes are especially important when rammed linings are used.

Many methods are used to dry iron and steel ladle linings. In some cases a wood or charcoal fire is built in the ladle as soon as it is lined and the fire is gradually increased until the lining appears to be dry. It is then allowed to cool to room temperature and washed with a clay daub.

Some ladles are dried over a coke fire. For others, a mellow flame, from a gas torch, is applied to the newly lined ladle (Figs. 1 and 2). Some cracks usually develop, but they are closed with ladle mud when the ladle is apparently dry.

A number of foundries now are using core ovens for drying ladles, and this appears to be the preferred method. Hand ladles, bull ladles, crane ladles, and even ladles up to 4 tons capacity, are being dried in core ovens. The temperature in these ovens will run from 500 to 600° F. The linings are heated slowly and uniformly, all of the free water is driven out and the ladles are in excellent condition for immediate preheating or for storage in a warm, dry room. After storage, the ladles must be preheated before using.

#### Methods for Preheating Ladles

After the ladles are thoroughly

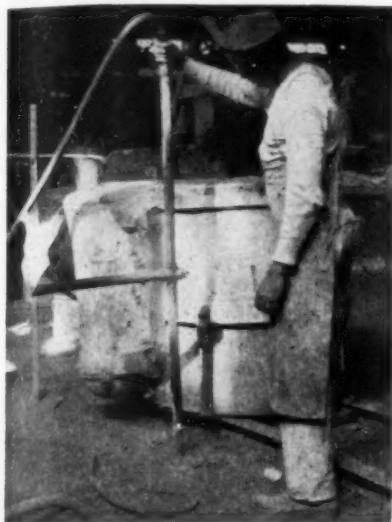


FIG. 1—GAS TORCH FOR PRODUCING A MELLOW FLAME IN SLOW DRYING OF A NEWLY LINED LADLE. NOTE FLAME ISSUING FROM "T."

dried, it is necessary that they be preheated to remove the chemically combined water from the refractory lining. This is done with oil or gas torches (Fig. 3), with the ladles preferably in a vertical position.

Many ladles are preheated in a

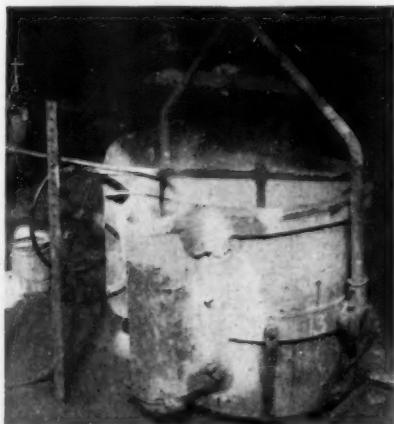


FIG. 2—GAS TORCH SHOWN IN FIG. 1, PLACED IN LADLE.

horizontal position using a wall type heater (Figs. 4, 5 and 6). While this method is effective, the ladles have a tendency to go a bit out-of-round. Also, the lining sometimes flakes off and the ladle trunnions and gear mechanisms do not maintain mechanical alignment.

From the standpoint of lining stability, the vertical method of preheating is recommended, even though it has some disadvantages. In the vertical preheating method, it is difficult to drive the flame from the oil or gas torch down into large ladles. Also, considerable fuel may be wasted and, unless sufficient secondary air can get into the ladle, a reducing atmosphere will be present in the ladle, carbon will be deposited in and on the lining, and some damage may be done to the refractory materials.

Foundry equipment engineers now are making improvements in ladle preheaters by placing a cover around the burner and over the ladle. The cover is lined with plastic refractory and reflects heat downward into the ladle (Fig. 7).

#### Improved Method

An improved preheating method was published anonymously in the May, 1942, issue of the British magazine, "Iron and Steel." The equipment has been in operation for several years and has resulted in speeding the preheating operation and reducing cost by half (Fig. 8).

This equipment was designed for gas, but it is felt that oil could be used equally as well. It consists of a shield, lined with plastic refractory, which can be lowered into contact with the ladle top, thus conserving heat.



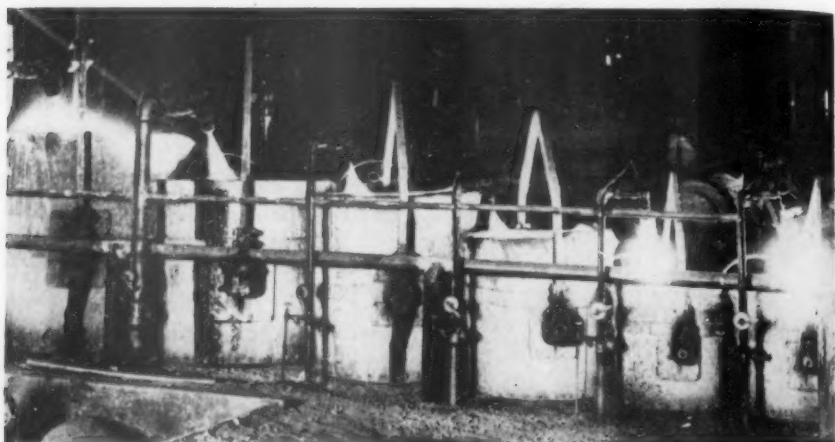


FIG. 3—BATTERY OF TORCHES FOR PREHEATING LADLES IN A VERTICAL POSITION.

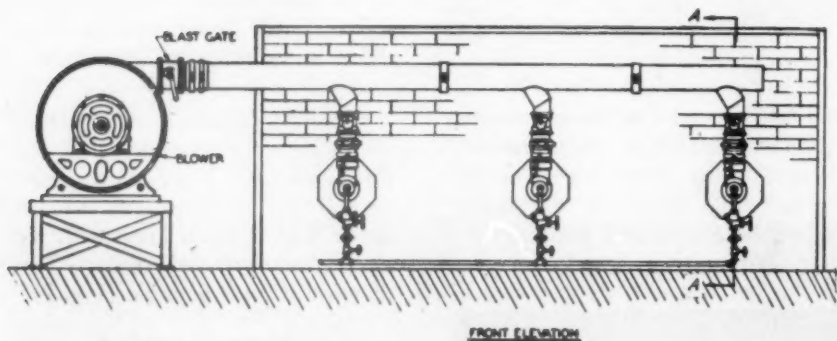


FIG. 4—GENERAL LAYOUT OF A WALL LADLE PREHEATER.

A means of escape for the burned gases is provided by two chimneys, symmetrically placed in the shield. The shield was made flat, instead of conical, for the sake of simplicity.

If this device were fired by the ordinary type of burner with a single central air supply, the gas would not burn in the ladle because it would lack secondary air. Instead, it would emerge from the top

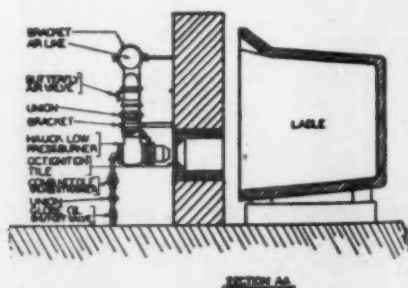


FIG. 5—CROSS SECTION OF WALL LADLE PREHEATER AT "A" OF FIG. 4.



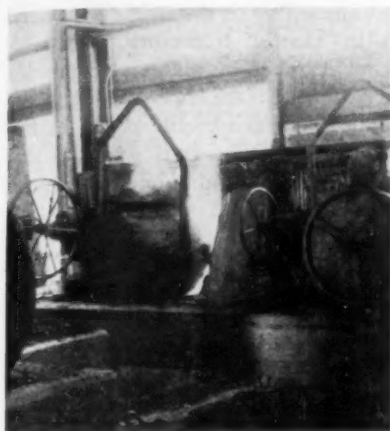


FIG. 6—LADLES BEING PREHEATED IN A HORIZONTAL POSITION AGAINST A WALL HEATER.

of the chimneys and burn there. This difficulty was overcome by providing the burner with an outer air jacket, as in burners designed for use under water.

The air supply was taken from the

compressed air mains at 75 psi. As this pressure was unnecessarily high, a saving in compressed air was effected by fitting two simple air injectors by which the high pressure air sucked in atmospheric air.

The equipment is easily controlled. Sufficient air is supplied to the outer jacket to keep the flame inside the ladle. The intensity of the flame is controlled by adjusting the central air supply. When the central air supply is reduced, the flame becomes soft and luminous.

To protect the burner, and also to ensure that the flame extends sufficiently toward the bottom of the ladle, a loose sleeve may be slipped over the burner tip and may be replaced from time to time. This refinement has been found to be well worthwhile.



FIG. 7—IMPROVED LADLE PREHEATER. THE COVER IS LINED WITH PLASTIC REFRACTORY.

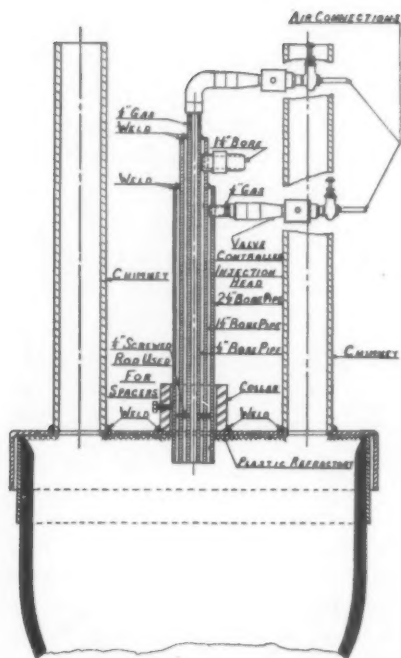


FIG. 8—LADLE PREHEATER. NOTE CHIMNEYS FOR THE ESCAPE OF BURNED GASES. BURNER IS PROVIDED WITH AN OUTER AIR JACKET, AS IN BURNERS DESIGNED FOR USE UNDER WATER.

The inside of the shield is covered with plastic refractory, which is kept in place by pieces of expanded metal which are tack-welded to the bottom surface of the shield at frequent intervals. It is essential that this refractory lining be kept in good repair to avoid distortion of the shield.

The authors appreciate the data and co-operation given to them in the preparation of this paper by H. S. Austin, J. A. Bowers, Wm. Berlin, A. C. Denison, George S. Evans, E. A. Frey, Norvin E. Green, John Grennan, Henry C. Griggs, H. S. Gulick, Harry Hazeltine, Arthur C. Hintz, Joe Manning, E. C. Miller, Earl F. Minnear, A. McMeekin, C. W. Phillips, Donald Reese, R. L. Salter, Bill Setzer, F. John Schwenk, H. A. Smith, J. C. Thomas, Milton Tilley, Charles C. Trenary, C. L. Williams, C. O. Williamson, J. Harold Winn, and C. S. Whittet.

## DISCUSSION

*Presiding:* C. K. DONOHO, American Cast Iron Pipe Co., Birmingham, Ala.

*Co-Chairman:* E. J. CARMODY, Chas. C. Kavin Co., Chicago, Ill.

VICTOR PASCHKIS<sup>1</sup> (*written discussion*): In the presentation, the authors mentioned the necessity of preheating ladles to avoid cracks because of the sudden heating caused by the liquid iron and to avoid chilling the iron. The authors stated that, at present, it is not possible to determine the necessary time for preheating which would insure sufficient "soaking" of the ladle with heat.

The problem of correct preheating can be divided into two parts. First, it is necessary to know what temperature distribution is desired in the lining and to what extent temperature increase by the liquid iron may be tolerated.

The second part in this problem consists in selecting a preheat temperature and preheat time which insure the results desired. The best preheat temperature and time depend on the size of the ladle, the thickness and thermal properties of the brick and the pouring temperature of the iron. If these values are known and the desired conditions as explained in the previous paragraph are given, preheat temperature and time can be determined conveniently by the electric analogy method\* which has been explained in a paper presented at this Congress.

<sup>1</sup> Heat Transfer Laboratory, Columbia University, New York.

\*Paschkis, Dr. V., "Heat Flow Problems in Foundry Work—Survey Method of Solution," *TRANSACTIONS, American Foundrymen's Association*, vol. 52, pp. 649-670 (1944).

## The Young Engineer in Foundry Production

By C. L. HEATER\*, CHICAGO, ILL.

### INTRODUCTION

1. If this were an ordinary spring, a peacetime spring, the talent scouts would be out in force. Some would be watching college and high school baseball teams, looking for future Gehrigs and DiMaggios. Others would be dropping in on spring football practice, hoping to discover another Red Grange or Tommy Harmon. And still others would not be near the playing fields at all. They would be hobnobbing with their old professors, lining up, in advance, promising technical talent for industry.

2. There is only one thing wrong about this pleasant picture of normal springtime scouting. Representatives of the steel industry would be on the ground—and of the chemical industry—and plastics—and electronics—and many more. But, judging by the past, one industry, with which we are all well acquainted, would be conspicuous chiefly by its absence. I will leave you to guess which one.

### OPPORTUNITIES OF THE FOUNDRY INDUSTRY

3. Or I might give you a clue. I want to recall to you the splendid address by John H. Van Deventer<sup>1</sup>. Many of you probably heard that address, or you may have read it—but I want to quote a portion of it here, and earnestly commend it to your serious consideration. It bears directly on the need I am here to discuss tonight—it gives a wise and broadly experienced outside viewpoint on that need. I am sure that it will be helpful if I repeat these significant words of Mr. Van Deventer:

"I do not think that any man or any business concern, including foundries, knowingly works for nothing or loss. The conclusion, therefore, must be that lack of knowledge is the cause of this unfortunate condition. And the one way to counteract that is through education.

"But this process of education must be internal as well as external. The radiograph reveals you as deficient in the growth vitamins represented by a flow of incoming technological talent.

"I have heard many young engineers in our professional schools say, 'I am going into the steel industry for my life-work, or into the chemical industry or the plastic industry, or aviation or electronics.'

\*Vice Pres., American Steel Foundries.

NOTE: This paper was presented at a Session of Engineers in the Foundry at the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

<sup>1</sup> President and Editor, IRON AGE. Address delivered before the Chicago Chapter, American Foundrymen's Association, February, 1944.

I do not recall having heard any of them say, 'I am going into the foundry industry.'

"This is not a healthy situation, and when an unhealthy situation exists there must be a reason for it.

"The reason for this, as I see it, lies within yourselves.

"Promotion and public acceptance of any industry or any product must come from within and start at home. The better mousetrap idea may be good literature but it is not life. Unless you believe that your industry is an up-and-coming one, and believe it enough to get as full of enthusiasm about it as a hill-billy does of corn—and act accordingly, you can not expect the general public to pay much attention.

"If I did not honestly believe that you have exceptional opportunities ahead of you and that realizing them will be good for not only you but for industry as a whole, I would not be taking the time, nor running the risk of sticking my neck out to make these critical remarks. But I do honestly and sincerely believe that because of what has happened during the past few years, you are now in position to put your industry upon a new and distinctly higher plateau of service, profits and public acceptance."

4. I feel that we all ought to be grateful to Mr. Van Deventer for "sticking his neck out." I think his criticism of our industry is fair—and constructive. And I also feel that he has given us a stimulating picture of the opportunity before us—the opportunity, again quoting his words, "to put the foundry industry upon a new and distinctly higher plateau of service, profits and public acceptance."

#### *Value of Technical Training to the Foundry*

5. One step toward that objective is, beyond a doubt, a continuous infusion of technically trained young men. And while I am here to discuss the advantages that flow from the employment of young engineering graduates, I would like to point out in passing that similar advantages are gained by recruiting technically trained men in other specialized branches, such as metallurgy and accounting.

6. Naturally, the first question which needs answering in considering young engineers for the foundry industry is, "What can they do for us?" My broad answer to that is that they can do for us just what they have done and are doing for other technical industries. To be slightly more specific, and to paraphrase the American Society of Mechanical Engineers' definition, "An engineer is one who makes practical application of the determinations of science." To do this, engineers have been trained to seek problems and approach them logically, to appraise a problem as a whole, then to break it down into its fundamentals, and from there work toward a solution. The specific technical knowledge which they have acquired, such as the strength of materials, applied mechanics, thermodynamics, hydraulics, stress analysis, calculus, and other mysteriously named branches of technology, is useful and

necessary for arriving at final solutions in many cases, but it is useless and confusing unless the basic approach to a problem is sound.

7. Primarily, therefore, the engineer can serve the foundry industry by bringing to it a mind trained to a fundamental approach to our problems, to a logical appraisal of all of the elements involved, and to organizing and following an orderly program for their correction. And then, since so many of our problems are predominantly technical in their nature, the specific knowledge acquired in engineering education comes in most usefully in effecting a solution.

8. A young man equipped with a sound fundamental engineering training is a man who should be able to learn the details of foundry operation much more rapidly than one not so equipped. He, therefore, gives his employer wider possibilities of usefulness than the less fortunate chap who must learn each phase of operations the hard way. I do not imply that the trained engineer will make a better core-room foreman, or foundry foreman, or melter, or pattern foreman than a man who comes up through one of those departments and finally demonstrates his ability to handle the job. But I am convinced that an engineer can more quickly become one of those foreman and can more readily be shifted from one such job to another than a man who does not have the same technical and fundamental training. The fact that he has mastered a sound engineering course is in itself partial indication that he has enough native intelligence to readily grasp the peculiar details of foundry technique and progress to greater responsibilities.

9. I do not mention the importance of the engineer in joint cooperative design effort with customers, to assure them a better casting for their job and the foundry a better casting to make, for that seems to me to come within the province of the engineer in casting sales. But that engineer will be more successful if he is working with an engineer in producing the castings.

10. If these basic qualifications of young engineers are not sufficient to make you feel that their employment holds advantages for the foundry, I suggest that you consult other successful industries for their experience. The best demonstration of the policy that has evolved from that experience is to be found—as I pointed out in my opening remarks—on the campus of any engineering school during the spring of normal years. Representatives of enterprises, both large and small, are there looking over the current graduating crop, making selections, and endeavoring to line up their yearly quota of prospective supervisors, managers, technicians, and executives. They do that because they have found that it pays. And they get the man they want, the cream of the crop, because of what they have to offer in return.

#### WHAT THE FOUNDRY INDUSTRY HAS TO OFFER YOUNG ENGINEERS

11. Now, if we reach the point where we decide to recruit engineers for foundry employment, we must determine what we have to offer, to attract able, ambitious young men to our industry. And I feel that we can offer much,



if we start with the deep conviction that we need new talent, new thinking, and sound objectives.

12. First, our industry is changing, and young men can take a great part in accelerating this change. It is a change from a commodity industry to one of engineered products to meet specialized requirements. It is a change which engineers have demanded and which engineers can best aid in carrying on. Second, our industry holds possibilities for growth, and that carries appeal for youth. Third, the foundry industry is not highly centralized; so the field for opportunity is not restricted. Fourth, we are not highly organized, technically; so progress based on merit should get prompt recognition and not be dependent upon slow changes in mature organizations. Fifth, the foundry industry is a man's business, it is tangible and real, and this appeals to the type of men the industry can use. Sixth, there are good opportunities for substantial rewards in our industry. It does not have many get-rich-quick possibilities, but it should be as attractive from a career and salary standpoint as any other major branch of industry.

13. Counteracting these appeals, we must also recognize that foundries have some less desirable features from the standpoint of the young engineer. We have not publicized our industry as a field for progressive young men—we are not thought of as a promising field for a lifetime job. Note what the aluminum, telephone, and electrical manufacturers are doing along this line. As an industry, we have been slow to see that our product gets its fair share of attention in the engineering curricula of technical schools. Our house-keeping has not made our plants the pleasantest places in industry. But these are largely defects of omission, which energy and determination will overcome; and they will not greatly retard obtaining the right sort of men once we decide we want to get them.

#### SELECTION OF MEN

14. With confidence in our industry as a growing factor in American enterprise, and a belief in the desirability of injecting larger numbers of engineers into it, we should give the most careful attention to the selection of men. If these engineers are to be of greatest usefulness and capable of advancement to responsible positions, their selection should merit at least as much study as we might give to a new sand-handling system or motor truck or core oven. Picking the man should be an executive responsibility, shared by the heads of the principal departments of the firm, and it should be done seriously and carefully. Try to remember that you are selecting men for careers, not just for jobs. The preliminary selection should be made at the school and should be followed by an interview at your own office or plant in which all the executives concerned should participate.

15. To be successful as a foundryman, the man you choose should be in good, sound health, with fairly broad interests rather than intense, narrow ones. He should have mechanical aptitude and reasonable ingenuity and



imagination; be willing to work as well as to think; and have confidence in his ability. He should be able to remain stable under pressure, work well with a wide range of personal types, and command the respect of his associates. And he should have a reputation for good character and give evidence of possessing naturally sound judgment. His scholastic attainments, measured by his college grades, are not of first importance except when viewed along with his other collegiate achievements. A man who has kept up with the average and has worked to help himself through school or participated in group activities is to be preferred to the one who may lead the class scholastically but who has done nothing else during his school career. It also does not seem to me to be of great importance whether he has taken a civil, electrical, mechanical, chemical, or any other special engineering course. Each has its benefits, but sooner or later the foundryman needs to be a bit of all of them. Also, it does not seem to me important whether he has been graduated from a large or small, or a famous or less well-known school. The important factor is whether or not he has learned the basic fundamentals of logical thinking.

#### *Cooperative Engineering Courses*

16. I do not offer this as more than a personal opinion, but from my own observation I am inclined to favor the cooperative engineering courses for foundry operating personnel. There the men work while they learn; consequently, on completion of the course, they are already pretty well trained—if they have been intelligently handled—in the elements of the industry where they have been employed during their scholastic period. Also, they generally are compelled to work their way through school and probably gain a keener appreciation of the value of work and of the opportunity to become well established.

#### *Foundry Training Period*

17. Regardless of the school or course pursued, it is most essential that a careful, well-planned program of training be followed *after* you have hired your man. Again, this is important enough to justify executive planning, supervision, and follow-up. As an example, assuming he knows little about a foundry, start him off with several days under the wing of one of your general supervisors who can give him a broad picture of the operations involved. Then lay out a program covering, say, a year or perhaps more, in which he will spend several weeks in the molding department, core room, cleaning and finishing, heat treating, pattern shop, sand conditioning, melted metal department, and even longer in casting inspection.

18. Many favor the inspection period first of all, for that is a great place to learn what foundry problems are. Most employers who have such training programs require a report at the end of the trainee's period in each department. This is principally for the benefit of the man himself, for it forces him to review his experience and frequently shows him some points that he has not

covered as thoroughly as necessary. After a period with the accounting department and perhaps with the plant maintenance gang, the man should be in a position to start paying you a dividend on your investment. Until then he probably has not been holding his own so far as productive effort is concerned, for if he has been properly scheduled, he has been moved on from one department to another as promptly as he has familiarized himself with its processes and operations.

19. But when he has finished his period of acclimation, observation and training, he should be ready for minor supervisory assignments or as a staff assistant for special detail assignments. From there on he should expect no favor, but should be able, by virtue of his engineering training and his quick special foundry training period, to move forward into increasingly responsible positions with greater rapidity than those without such benefits. I can say this confidently because, where this policy has been tried, it has proved successful; not 100 per cent successful, but with a high enough degree of success to amply justify any higher costs involved or effort expended.

20. I realize that some of you may feel, quite reasonably, that with this suggested plan of training in the foundry for a man with the qualities recommended, it should be immaterial whether he has had a college education or not. Of course, that is true, but the hitch is that men with such qualities are not to be found on every street corner. They generally realize the benefit of a good education; hence they are to be found in larger numbers in college graduating classes than in any other groups of men looking for job opportunities.

21. Since I have gone pretty well into details, I might also say that compensation should be based on the current market for engineering graduates when a man is first hired, with a nominal increase possibly six months later if he indicates promise. Then after his training period, pay him what the job he does justifies. And then, since he is a potential executive, pile on the responsibilities and the corresponding authority just as fast as he can take it. More young men are lost through lack of utilization of their capacities than from overloading them. But pay them for their job when their job grows. Do not make the mistake that is made by some large companies, who have hired large numbers of engineers each year and treated them as a pool of cheaply paid, high-grade help. Ultimately this defeats the objective you are trying to achieve.

### *Research*

22. Another thing which merits mention is the engineer's attitude toward research. The employment of young engineers in the individual foundries which make up our industry will spur technical research for the industry, and will also greatly hasten the practical application of its findings in your own company, for the engineer knows that he must look forward as well as back. He is not content to use a process or follow a procedure merely because of

that good old foundry reason, "That's the way we've always done it." Certainly none of you will disagree with the statement that we need research and need acceptance of its findings.

23. Let me quote again, this time from an interesting article by Fred P. Peters\*:

"If foundries are backward technically (as is widely believed), then such backwardness is almost a fundamental flaw in our industrial structure. If, however, the foundry industry is progressive (as is actually the case), if it utilizes new scientific concepts and modern engineering practice, and if it has provided its own solid base of forward-looking research and development, then we may expect its influence in the American scene to grow and the market for castings to expand continuously."

#### CONCLUSION

24. To add one more "if" to those of Mr. Peters, I believe that if we grasp our opportunity to acquire our share of engineering graduates for service in our industry, we will take a constructive, forward step toward the objective of that "new and distinctly higher plateau of service, profits and public acceptance."

25. Yes, I believe—in fact, I know—that we will go a long, long way.

(For discussion, see page 1305)

\*Peters, F. P., "Casting's Progress," SCIENTIFIC AMERICAN, March, 1944.

## The Place of the Engineer in the Foundry

BY L. J. FLETCHER\*, PEORIA, ILL.

### INTRODUCTION

1. Let us examine this title before diving in. What is meant by an engineer? For the purpose of this discussion, the term "engineer" will refer to the young college graduate in mechanical, metallurgical or some other basic engineering course. The young engineer, we assume, will know well his fundamental sciences, such as physics, chemistry, mathematics, materials and the other scientific subjects closely related to his major field. He may or may not have any knowledge whatsoever of foundry practices. As for the term "foundry," we will consider the entire enterprise, from the purchasing of materials to sales and collection.

2. You properly may ask, "Why represent the engineer by an inexperienced, untried graduate full of theory and questions about the foundry business?" There are two reasons. First, the new graduate from a good engineering course is a fairly "standard package" as far as knowledge is concerned. Second, education is not a matter of years in school or college, or of academic degrees. No one has ever received an education. Everyone is self-educated. To learn requires study, and study is work. No one can supply this work but the learner himself, and this work may be done in many places and under many circumstances. True, a college professor helps to point the way and judge the progress. When an engineer has reached the place where he has demonstrated his technical skill in the solving of the world's problems, we are but little concerned with how or where he gained his ability. In fact, it has been said that engineering is simply an orderly or systematic way of thinking or acting, just as science is sometimes defined as "organized knowledge."

### ART, CRAFT AND SCIENCE

3. Right here is a good place to present one of the major factors facing any engineer inexperienced in the foundry business, be he young or old. A foundryman represents one of the oldest crafts or arts in the world. The early history of the casting of metals is lost in antiquity. In common with all other arts, the foundryman has carried his share of craft or trade secrets or

\*Director of Training, Caterpillar Tractor Co.

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traditions, but, as in other arts, to the craftsmanship of the foundry there is now being added the contributions of the scientist.

### *Science in Agriculture*

4. Let us compare the foundry with even an older art or craft—agriculture. Only within the past century have fewer than one-half of the working people of any country devoted their energies to other activities than agriculture. It is the oldest and the largest of crafts. How did they do before science came along to team up and pull its share of the load? Livestock died of plagues, crops failed or blighted, famine was the constant fear of every people.

5. A Harvard economist, E. M. East, wrote in 1923, in his book, *Mankind at the Cross Roads*, "The world will be filled with people without faith or hope, a seething mass of discontented humanity struggling for mere existence, within the span of a single life time. . . . This is the world question. It is a question of reducing a swiftly increasing population to fit a rapidly diminishing food supply." Mr. East could forecast the "art" of agriculture but not the application of the unpredictable "science" of agriculture.

6. We would not have our ample supply of bacon and ham today if agriculture had remained a craft. The cure for hog cholera was not discovered on the farm but in the laboratories of bacteriologists and chemists. All the legions of plant and animal pests and diseases would march unopposed across this land if they were not held in check by the timely and correct application of sprays and dusts and dips. The control for each of these pests called for patient and exact application of scientific facts which previously had been discovered and unselfishly recorded and published so that others could carry on.

7. Scientists interested in plant breeding have developed varieties of wheat and oats resistant to smut and rust. It is likely, also, that the young mycologists who collected the spores of these fungus diseases in the fields of wheat and oats might have failed miserably as binder operators or in tending a grain separator.

8. Corn growing has received the earnest attention of millions skilled in the art of growing this most important crop. Yet, in recent years, men applying the science of genetics developed hybrid corn which has resulted in a 25 per cent increase in corn production in our Corn Belt. These few scientists could rightly accept the credit for our present ability to feed ourselves and the millions overseas.

9. Did the farmer welcome these scientists with open arms? No. Thirty years ago the agricultural college graduate, the chap who farmed out of a book, had to take a great deal of unfriendly criticism from most farmers. The craftsman seldom welcomes the scientist. He who knows "how" but frequently not "why" has always feared to lose his place. The scientists will not, in fact can not, displace the craftsman. Each needs the other. Only through the most complete and sincere cooperation can they together push forward any industry.

*Foundry Training*

10. Coming back into the foundry, through what avenues of training or education do men arrive at jobs or positions of importance or responsibility? First, there is the man who just "got a job" in a foundry—any job, likely learning the art of handling a shovel. He observed what went on about him, learned by doing and, in time, was upgraded progressively to more important work. His own ability, initiative and resourcefulness set the limit of his rise. Second, there is the apprentice. He, too, learns by doing, but he has the help of the instructor and benefits much from related classroom instruction. The apprentice is given every opportunity to learn the "hows and whys" of foundry practices and to continue to add to his knowledge after completing his apprenticeship. And then third, the engineer. He comes to the foundry knowing scientific facts—facts which will not change, laws of physics, laws of the behavior of metals. We call this kind of knowledge theory. If he stays in the foundry he (somehow) learns to apply this theory to the solution of certain types of problems, and he learns a great deal more in addition, mainly about getting along with people.

11. With these three types of training—one, upgrading; two, apprentice, and three, engineering, let us analyze more carefully the business of the foundry and see if there is any logical way to determine where each fits. Here the foundry will be divided into ten divisions. We will line up these divisions on the basis of the qualifications of the men who will supervise the work and handle the most responsible jobs in that division.

*Foundry Work Classified*

12. First, therefore, in what type of foundry work will we most likely find in charge the No. 1, or upgraded man? In the biggest job of all, (1) Production. Here is employed most of the men. Material must be moved; the equipment kept busy; it is where we "get out the iron." Production here is used in a restricted sense. It might be called the "smooth running" or trouble-free production, keeping things going when things go right. Then our No. 1 man often shows up in the (2) General Management of a foundry after, it is true, much self-education.

13. Now for the experienced apprentice graduate. He has many places. We will start with (3) Personnel work, such as hiring, safety, job classification, rates and the like. Then (4) Training of all kinds, including supervisor conferences. He should find a place of importance in (5) Purchasing, where his knowledge of the materials used in the foundry is most useful. In the (6) Control activities such as inspection, methods, trouble shooting and the like. The apprentice should be well suited also for the job of (7) Production Planning.

14. There are seven of the ten divisions and no engineers yet. Well, here is their list. One of the main jobs is (8) Research, the search for new or



better products, new methods and materials; the solution to the many problems arising, for example, in the machining of castings, or for those heart-to-heart talks with the engineering or designing departments. (He talks their language. They can not scare him with engineering jargon.) Next, the engineer, with his knowledge of structural design, should serve well in the (9) Equipment field. This includes the design of new devices or structures, changes in design, installation layouts and certain types of maintenance. And then in the (10) Marketing of the product, the engineer will find a place in aiding the customer to make the best use of the facilities or product; in fact, his training suits him well for sales, advertising and even financing.

15. Now, just a minute, please. I know that most of you are not in complete agreement on from one to all ten of the above allocations of types of trained men. I am not going to argue with you. This analysis was made simply for the purpose of arousing thought as to where the engineer does fit into the foundry. He belongs somewhere. There is a job for him to do. The foregoing method of analyzing, if applied to a definite foundry, taking into account every influencing factor, could well show where the engineer might be needed. Remember the corn farmer. He knows just what it takes in machinery, power, labor and materials to plant, cultivate and harvest his fields of corn. That calls for a good knowledge of farming on his farm. He would not know what to do with a geneticist; in fact, he did not for many years. But, finally, the geneticist got an idea; he started in under the questioning gaze of the farmer and came up with hybrid corn. Now, the same land and the same work produces 5 bushels where 4 formerly grew, and remember that the farmer was satisfied with 4 bushels.

#### *Applied Science in the Foundry*

16. You wonder where this farm and foundry inspection tour is going to lead and why we start out with the young engineer. Because, one, the foundry should start out with the young engineer and bring him up in the business. Two, learning from the other ancient craftsman, the farmer, who is fast becoming a scientist, the foundrymen must increase their faith and confidence in the productivity of applied science.

17. Here are two suggestions which should help get productive work from the engineer in the foundry. One, start him off right. I know there are good reasons why this start might well consist of a "shovel in the hand and a kick in the pants." You want to show him that there is work to be done in a foundry. You want to see if he can take it. Well, who gains if he can not take it, or even if he *can* by the "sink or swim" method. This young engineer had something on the ball to finish up a stiff four-year engineering course. Two out of every three who start in engineering fail to finish. He wants to learn how to apply what he knows. He is not afraid of getting dirty. Most young engineers prefer the kinds of jobs that "come off on the clothes." It is altogether the attitude toward him that counts. He will work hard and

like it if there are reasons—if he is working to some end, for some purpose. Is he treated like a pest, or in an understanding way when he asks questions on some new job? It may be he asks too many “whys.” How many of you would like to have a doctor operate on you, whose internship had been served in a hospital where the experienced doctors took the same interest in the new medical graduate as the interest shown in the young engineer in the typical foundry? (I know that yours is different.)

*Development of the Engineer in the Foundry*

18. Try this. After the young engineer has become acquainted with foundry operations, select one or two problems requiring engineering knowledge and experience. Let them be way over his head, if necessary, but give them to him. He will make better progress, work harder and be happier working on engineering or scientific problems than on any other kind of work you can put him. You may think it a waste of time but, before you cross it off the list, try it once, anyway. If you have done the right kind of a job in selecting your man when you hired this young engineer, he will surprise you. Give him engineering responsibility. That is the way to develop him.

19. The other and concluding suggestion as to how to get productive work from your young engineer has to do with getting the engineer into the foundry in the first place. Why not change the display in the show window? What do I mean? How do foundrymen describe the foundry job when young engineers are within earshot? “If you like hot, dirty work, get yourself a job in a foundry,” is the usual style. A variation is, “Are you sure you want a foundry job? It is real work and lots of it. No white collars.”

20. Why not tell the whole truth. Of all the occupations of which I know, those engaged in foundry work have the greatest attachment to their job environment. They love it. The foundryman loves the smells of burning core oils, the action, the hot metals, the feeling of accomplishment that comes from creating sound castings from the piles of scrap and pig and coke and limestone and sand. It is the love of the true craftsman for his craft. The foundry, at work, is a living, dynamic, coordinated force. Gentlemen, you can offer this young engineer the opportunity of serving with his science a great industry, the foundry business, and, in return, you will give him the privilege of becoming one of you.

## DISCUSSION

*Presiding:* C. V. NASS, Pettibone Mulliken Corp., Chicago, Ill.

C. J. FREUND<sup>1</sup>: What is the sum total of time which is devoted by the college graduate to that successive training program in the various foundry departments?

MR. HEATER: That depends on the individual plant, the variety of work that they make, or I should say the individual company, which might include several plants, each of which is following slightly different practices. If you want to give them a full training, it would involve covering all of those plants. I think that a year in a normal size foundry, and in a normal type of production, ought to give them a general idea of the foundry business. There is no royal road to learning the foundry business. Perhaps some of you could cover the operations of your own particular plant in 6 months, and another plant might take 3 years. It should be broad enough so that the man will get a comprehensive idea of the operations that you expect him to participate in and, ultimately, to take part in directing, and it should be short enough so that he does not get into a dead end, doing repetitive work where his talent is not utilized to any extent.

W. M. SHEEHAN<sup>2</sup>: I am not the least bit concerned about finding a useful place in the foundry for the young engineers. The foundry art probably has had less science applied to it than any of the mechanical arts, and I believe one of the principal reasons is that we have not attempted to sell our industry to men who are being scientifically trained.

We should not bring these men in and coddle them. We must make the opportunities that the foundry art has to offer appear in the romantic light that it really has.

A realization has recently come into the minds of designing engineers that gray iron is a real mechanical engineering material. And why is that? It is because of the application of scientific principles to the gray iron foundry industry.

I will not attempt to go into the non-ferrous casting field, but certainly in the steel castings industry there is a tremendous opportunity. For most purposes, I think we will agree that a steel casting, properly made—and that is the only kind that should be made—is better than a forging, is better than most fabricated welded products; and if we can get young men with the proper foundation to come into our industry and learn something about it, and thus be in a position to apply some of the scientific knowledge that they have acquired, we are not only going to do a great thing for the foundry industry itself but we are going to give those young men, as Mr. Heater said, an opportunity for a career.

CHAIRMAN NASS: With the rigid specifications which we have to meet in the foundry industry today, inspection by radiography and magnaflux, and with metallurgy still in its infancy, if we are going to progress as we should we must have trained engineers, trained technicians, and trained scientists. I believe that as a group we must do a job of selling the foundry industry that will bring the trained men that we need to the industry.

MEMBER: As to engineers in the pattern shop. Do you mean in the pattern shop or the pattern department, the designing of patterns?

MR. HEATER: I believe that an engineer could make a very good pattern maker, if you want to keep him there. He ought to make a much better pattern maker than a man who has just served a pattern apprenticeship, because he knows far more of the ramifications of why there is a pattern in the first place. I think it would be a waste of an engineer to leave him in the pattern shop. And when I say the pattern shop, I mean actually producing patterns. Certainly he would be better designing patterns than

<sup>1</sup> Dean, College of Engineering, University of Detroit, Detroit, Mich.

<sup>2</sup> Asst. Vice Pres., General Steel Castings Corp., Eddystone, Pa.

building patterns. Certainly he would be better as the pattern foreman. Certainly he would be better as the next step, the general superintendent of the foundry and the pattern shop, and from there on up as he moves ahead.

I do not suggest that you use engineers and confine them to any of the minor jobs for good. But where do you get the men for your higher jobs? You get them out of the men who are holding the minor jobs, and unless you have some good men in minor jobs it is going to be difficult when there is a higher job to fill. That is why I say that engineers can be used in the pattern shop or the core room or any other place. They ought to be able to serve very effectively in any of those jobs.

CHAIRMAN NASS: Mr. Heater said that he felt there were at least equal opportunities for the engineer in the foundry industry. I believe that with the lack of technically trained men in the foundry industry, there are more opportunities in the foundry industry than in the other engineering industries, and there will continue to be until such time as the foundry industry is flooded with engineers.

F. G. SEFING<sup>3</sup>: I presume that everyone who came here came in the interest of engineers in the foundry. When it was suggested by one of the speakers that he hoped these talks could be given before those who are not much interested in engineers in the foundry, it made me think of the rather proverbial minister who is constantly berating the people who do come to church about those people who do not attend. Those men who are here are interested and it is certainly gratifying to see that the interest is becoming more and more active.

At the Committee meeting this afternoon, it was reviewed that for almost 20 years the Committee has been exciting interest for foundries in the schools and colleges of the country. We believe that a great deal of work along that line has been done, at least to the extent that the schools now say, "We do have young engineers for the foundry, but they just have a hard time getting a job." When this was first brought to our attention about three years ago, we began to take the other tack of running our activities over toward the foundries.

To that end, our Committee is hoping to work, and we obviously need the cooperation of you men in the industry and, of course, you men who are in the schools, and it is gratifying to see that we are making progress.

We do not expect to do this kind of a job in a year. Indeed, the whole program is an educational program, and those of us who have been in educational work know that it is a long, slow program. It takes in the neighborhood of 20 or 22 years to educate a boy into an engineer, and then he is only ready to begin to work, and it takes another 10 years to make a good foundryman out of him. Therefore, the whole program is a long-time project. Therefore, we have to be patient, but we believe that by working constantly and exercising a lot of patience, we will achieve the end that we are interested in.

However, these comments are projected way out into the future. The immediate problems are what can I do to get these men? How do I get one particular man? What do I do with him when I get him? It is one thing to say that you are going to put him into the core room for two weeks, but be careful that the core room foreman does not kick him out.

D. P. FORBES<sup>4</sup>: I do think that the engineering in foundries is a very important thing, and it is hard to attract engineers to foundries, and also, it is hard to educate a foundryman to know what to do with a young engineer when he gets him. As has been brought out, the problem must be approached from both angles.

<sup>3</sup> Res. Met., International Nickel Co., New York.

<sup>4</sup> Pres., Gunito Foundries Corp., Rockford, Ill.

MR. SHEEHAN: Mr. Forbes has put his finger on the two problems. One is that we have got to educate the educators who are attempting to educate the fellows that we want to help educate.

In talking recently with the dean of engineering of one of our largest universities, I was outlining to him what seemed to me to be the importance of getting technically trained men into the foundry industry, and he said, "Why under the sun would a college graduate want to go into the foundry?"

Seriously, that is the impression that many educators have. They have not the faintest idea of our industry, and I believe that one of the most important things that the Committee could do would be to draw up a specification to send around to these educators to tell them what the foundry business has to offer the trained engineer, and then to draw up another specification for the executive in the foundry industry to let him know what the technically trained men can do for his business and for his earnings. I believe that if we did that twofold job, we would make real progress.

CHAIRMAN NASS: There are very few colleges in this country that offer strictly foundry engineering courses. Mr. Heater brought out the point that eventually an engineer uses all branches of his engineering education in the foundry. I know that I have, and I am sure most of us have wished many times that we had had more civil, structural, electrical, mechanical and metallurgical work along with that in which we specialized, because there does come the day when we need it, surely, in the foundry industry.

MR. SEFING: With regard to the lack of college courses in foundry engineering, I believe that much more important than a course in foundry engineering is a good grounding in engineering, any kind of engineering. But somewhere in the college the student must acquire an abiding zest for getting into the foundry business. He may have all the necessary courses in a foundry engineering course, the finest that any school in the world can offer, but if he does not have this consuming desire to be in the foundry and to follow it as a career, he will be worthless to the foundry.

On the other hand, a young man who has been trained in civil engineering but who really sees a fascination in the foundry, any one of us in the industry can make a foundryman of him. So whether or not he has had a foundry training in college is not too important.

CHAIRMAN NASS: Mr. Heater, you mentioned in your paper that you liked the idea of cooperative engineering courses.

MR. HEATER: It is rather difficult to recommend to the foundry industry as a whole that it look to cooperative engineering schools for engineers to go into the industry, because there are not many cooperative schools. I believe that there are going to be many more. I like the idea because, along with theoretical training, the student is also witnessing in his alternate periods, actual applications of some of those theoretical things that he is learning about.

I would like to stress again that I do not believe that it makes much difference what kind of an engineering course is taken, and I am not absolutely convinced that it has to be engineering. What I like about an engineering course, and why I stress the hiring of young engineers, is because an engineering education is primarily a training in sound, logical, fundamental thinking, breaking down problems to their fundamentals before starting to solve that problem.

Now, when we talk about problems, I do not mean, necessarily, breakdowns or strikes or a heat that goes sour or anything of that sort. The whole foundry business is a problem every day, as is any other business. When I speak of problems, I speak of finding some way to do better those things that we are doing in our stupid ways from day to



day. After we find some other way to do it, we wonder why we did not think of that before. But that is why I like the idea of engineers for a foundry, because they have been trained to approach the solution of problems, or let us say every-day procedures, to analyze them, break them down to fundamentals, and from there try to arrive at more satisfactory means of doing those things.

So I am not too enthusiastic about very highly specialized training in the foundry business. As Mr. Sefing brings out, let us have more training in the analysis of problems and fundamental, good, sound thinking, and the details will come later when we start applying them to every-day practice. If you have access to students from cooperative schools, I do recommend that you look into those rather carefully if you are considering putting young engineers to work. Our experience with them has been successful, and we expect to utilize them considerably.

R. R. DRY<sup>5</sup>: When it was built, Buffalo Technical High School had a foundry in one of its shops. We have since had a course in metallography and we have a pattern shop. All of these shops are there for the purpose of acting as related fields to a major junior technical course.

The question I want to put is this: Is it desirable to have a full high school course in the foundry field in a technical high school? By a technical high school I mean a school in which the trade end is not emphasized but the junior engineering is emphasized; a school in which a five-year program might be an optional offering.

F. E. WARTGOW<sup>6</sup>: The Chicago Chapter of A.F.A. sponsors the foundry exhibit at the Museum of Science and Industry, and the foundry is being run by students from the Washburne Trade School as part of their training program.

MR. HEATER: I do not like the idea, unless you want to train them in a trade. I do not like very much the idea of getting an education in order to make a living. I like the idea of getting an education to enjoy a living. I believe that anyone who wants an education should be permitted to have it. I do not believe that anyone should be forced to have an education. In other words, it should not be given to them; they should get it. However, there is a place for it, but primarily the place for it is a vocational school rather than as a preliminary training to a technical course in a college.

I believe that the engineering training in the United States is becoming too specialized, too technical. We are narrowing our engineers too much, instead of taking the opposite tack and broadening them. I do not believe that engineers are going to be as good people as they ought to be if their education is confined strictly to engineering. Hence, I quarrel with the advisability of carrying that even further down the scale of education in the youngsters, where we ought to be trying to inspire them with a desire for knowledge rather than with a desire for training along some one specific line. It is all right if you want it as a trade school for those who are going to take that training for a vocation.

MR. FLETCHER: I would like to discuss the problem raised by Mr. Dry and also Mr. Heater's remarks on this matter of broader engineering education.

People become interested in different subjects at various ages. Young engineers are more interested in technical matters while older people become interested in human relations. Mr. Heater's experiences in his factory have caused him to become more interested in people, and he hopes he can get a young man who has learned, in some mysterious way, all about things and also all about people.

I have concluded that we learn about things from books, in the laboratory and in the

<sup>5</sup> Principal, Buffalo Technical High School, Buffalo, N. Y.

<sup>6</sup> American Steel Foundries, Chicago, Ill.



classroom, but there is just one place to learn about people and that is from people. There is no short-cutting.

Our age indicates our interest, and I think the place to do the job is where the interest is. The young man is interested in what we normally call engineering, that is, dealing with the forces of nature and materials and how to help mankind use them; and as we come along in years, we become more interested in folks. I believe that is somewhat the answer.

MEMBER: Many here seem to think that just a college student is good enough for the foundry. Every other industry takes college men and tries to make something out of them, and they always pick the one in their own field. Would it not be better to have a man educated in the foundry business?

MR. SEFING: I was asked to survey the various courses in engineering to find out what was the diversion between chemical, mechanical, electrical, etc. On the average, the diversion is about 20 per cent. In other words, all of the engineers take about 80 per cent of their work in common, and the difference is in such courses as bridges in civil engineering, corresponding to machine design with mechanical engineers, and electrical equipment with the electrical engineers. They are really educated along the lines of the general engineering program.

However, for a man who wants to get into the foundry business, it is the easiest to excite his interest by having a foundry at that school, showing him what some of the interesting features of foundry work are and pointing out some of the fascinating problems that can come up in a foundry.

DEAN FREUND: There is no question but that in engineering education there is a very pronounced trend, which will be discovered in revised curricula within 4 or 5 years, towards amplification of mathematics, chemistry, physics, hydraulics, statics, dynamics, materials, etc., and a very pronounced diminution of design courses, Diesel engine courses, internal combustion engines, steam power and all the rest of it. The engineering graduate of 6 or 7 years from now will be required to learn those detailed techniques pretty largely in the industries, and he will have a much stronger foundation than he now has in the larger and more basic, more fundamental things. The tendency is sharply in that direction, and it is going in that direction simply on the basis of experience which employers are having with their college graduates. It is a trend which is taking place in response to a very definite need.

Now, I know that the young boy, the first year he is out, wishes he had been taught more skills, because he feels that then he might be able to earn more, he might more successfully compete with others who have been longer in the business. That is a natural viewpoint, but it is not a sound viewpoint.

MR. SHEEHAN: I am opposed to specialized engineering training in the colleges. What our coming engineers need, in my opinion, is more basic science. Let them get the specialized training after they get out of college. I believe that the trend of engineering education is going to be in that direction.

We are talking about getting engineers into the foundry. I believe that our biggest job is selling the educators in the engineering schools as to what the foundry industry has to offer men. It is a most romantic industry. The 30 years that I have spent in this industry have been the most interesting that I could imagine. I would not exchange those 30 years for anything that this world has to offer in the way of industry. If we could just get that spirit of romance into the minds of educators, we would have no difficulty in recruiting the ranks of young junior engineers who want to learn the foundry business. The place to learn the foundry business is in the foundry, and an engineer can do a lot better in the foundry business than one who has not this training.

MR. FLETCHER: We are not dealing with a constant when we talk about a college graduate; we are dealing with individuals and individuals vary. I would say, from 12 years of experience as a college professor plus 17 years of industrial experience, that over one-half of what the graduate amounts to when he graduates, he brought with him into the school. He is the product of home training and environment. And when the man comes out of school, he is an individual. So do not think that if a college graduate fails in your foundry that it is a college graduate who has failed. It is an individual who has failed, or perhaps you have failed.

W. H. COULTER<sup>1</sup>: Seventeen years ago we decided to put an engineer into the plant in any capacity and see what we could do with him, and it happened that there were difficulties in the electro plating room at that time. In less than 6 weeks that engineer had adjusted the process so that we could take all of the electrical energy formerly going into the strip tanks for defective pieces and thus double the electroplating capacity. I do not see why we could not do the same thing for the foundry.

It seems to me that, in addition to selling the management on the idea of putting an engineer in the foundry, we will have to sell the management on the idea that the engineer is going to require some backing.

MR. FLETCHER: It is the function of a training department to give the young engineer a period of orientation training to cover, in an understanding manner, that transition period between the college and the actual productive work in the plant.

CHAIRMAN NASS: I believe that if management is not responsive to engineering in the foundry, competition will make it that way or there will not be any foundry.

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<sup>1</sup>Asst. Gen. Mgr., Coulter Copper & Brass Co., Ltd., Toronto, Ont., Canada.

## Report of the Subcommittee on Sintering Test, Foundry Sand Research Committee, 1934-1944

The work of the subcommittee during the past year has been a continuation of previous work, being primarily a study of the behavior of sand when in contact with molten iron. This work has not been as extensive as the study of sands in contact with molten steel, reported by one of the members of the committee last year, having consisted of microscopic examination of specimens of "burnt on" or adhering sand, collected from a few iron foundries.

All samples examined so far show the same mechanism of adherence that was found with steel sands, namely, penetration of the iron into the sand. Again this penetration was found to be mechanical, caused by too large voids present in the sand as rammed, due to fusion and the opening of large voids because of this fusion, or due to veining caused by dimensional instability.

The fact that all samples of adhering sand in iron practice, shown in this report, are due to penetration does not preclude the possibility of adhering sand due solely to fusion at the sand metal interface and no penetration.

A number of iron foundrymen claim that the latter mechanism has been observed in iron practice, but as yet have not submitted specimens. As the proof that it is necessary to have penetration in order for the sand to adhere to the surface of the casting is negative, it will be necessary to examine many more samples of adhering sand in iron practice before we can say that adherence without penetration is, or is not, possible.

### DEFINITIONS OF SINTERING DISCUSSED

The committee would like to call to the attention of the industry the exact definitions of the two sintering points now in use. Definitions may seem academic, but in this particular case they are very important, for they explain just what is occurring during the test. Indications are that almost the same action occurs when molten metal comes in contact with a molding material.

The definition of the "A" sintering point follows:

The "A" sintering point is the lowest temperature at which the surface of the sand specimen in contact with the platinum ribbon has sintered enough to adhere to the ribbon with sufficient force to bend it when it is lifted.

That for the "B" point:

The "B" sintering point is the lowest temperature at which the

NOTE: This report was presented at a Foundry Sand Development Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

smaller grains can be seen to start to fuse at low magnifications, 20 to 25 diameters. This is the point of incipient fusion.

These definitions emphasize one very important point—the sintering or fusion at the “A” and “B” sintering points is microscopic. This is where the sintering points differ the most from the classic tests for fusion, such as the pyrometric cone equivalent test.

The reason that the sintering test can be correlated with the behavior of the sand in contact with molten metal is due to this fact; fusion in microscopic dimensions can cause adhering sand. Penetration of the sand by the metal of just a few thousandths of an inch can cause serious “burn on” or adherence. Extreme cases of “burn on” or adherence will occur before an appreciable portion of the sand mass as a whole is affected.

#### A DIFFERENT VIEWPOINT

An important correlative of this viewpoint is that a number of variables will affect the sintering points and the behavior of the sand in contact with molten metal, having no effect on the classical tests such as fusion tests and pyrometric cone tests. Both of these latter tests determine the fusion of softening of the mass as a whole, and under conditions that approach equilibrium and infinite time.

The sintering test, on the other hand, is conducted, not under equilibrium conditions but under controlled disequilibrium conditions. This is important, as conditions in the foundry are such that equilibrium is never attained when metal comes in contact with molding sand containing silica or silicates, except in case of very massive castings.

The foundryman, accustomed to thinking of metals with sharp melting points, must change his viewpoint when thinking of silica or high silica silicates. These materials do not melt, as do metals, into liquid phases with viscosities approaching that of water.

On the contrary, liquid silica and high silica silicates, just above the liquidus line, are almost as viscous as when they are solid, and they must be superheated several hundred degrees before they become fluid in the sense that a metal is fluid.

This is doubly important when dealing with a material of non-uniform particle size, such as molding sand. Silica differs from a metal in another respect in that melting occurs only at the outside surfaces of the particle, whereas melting can occur within a particle or crystal of metal.

This means that, with increasing temperature, the smaller particles of a molding sand will melt and become fairly fluid long before the larger particles are affected by the heat. This is exactly what happens in practice when a sand starts to fuse. It is possible to have, what is for all practical purposes, complete breakdown of the sand and still have the larger grains of the sand unaltered by the heat.

Silica is just as sluggish chemically as it is physically. Therefore, impurities have a much greater effect on the sintering points and behavior of the sand in the foundry, when they are present in the A.F.A. silica phase, than when they are present as a separate phase in the A.F.A. clay fraction.

#### EFFECT OF TIME

Both of these variables, particle size and distribution of impurities have no appreciable effect under equilibrium conditions such as present in the pyrometric cone test. The big difference here is time or, to put it more exactly, disequilibrium.

Any other variable, when dealing with silica, in which time is a factor will also affect the sintering test and the behavior of the sand in contact with liquid metal, and will have little or no effect on the classical methods of determining the melting or softening points of silica.

The committee would also like to discourage the use of the terms "burnt on sand" and "burn on" to describe the condition of sand adhering to the outer surfaces of a casting, and substitute the terms adhering sand and adherence, since they would be more appropriate.

Terms using the word "burn" imply a heat effect, fusion, or at least sintering. In reality, heat, fusion or sintering is only one of a number of causes of adhering sand, some of which are simply mechanical and can occur with no heat other than that required to heat the sand to above the melting point of the metal.

#### MECHANISM OF ADHERING SAND IN IRON PRACTICE

Figures 1 and 2 show two examples of adhering sand from one iron foundry, and they are interesting because they show two mechanisms of adherence. Both samples were from the same castings, the only difference being that the two castings were poured in different sands.

Figure 1 shows the sand metal interface when a low sintering point sand was used ("B" point 2250° F.); the sand also contained calcium and magnesium carbonates. The smaller particles of this sand have fused completely, the silica grains have not been affected by the temperature of molten iron. Adherence in this case was serious, with the sand permeated by the molten iron.

Figure 2 shows the sand metal interface of the same casting poured in a high sintering point sand ("B" point 2700° F.). This is interesting because it shows what trouble can be expected if one simply increases the sintering point of the sand without taking into consideration the other causes of penetration.

The amount of adhering sand in this case is almost as great as when the very low sintering point sand was used, the only difference being that this sand could be removed fairly easily from the surface of the castings while that shown in Fig. 1 was almost impossible to remove. The adhering sand shown in Fig. 2 is due to mechanical penetration and may be due to the sand actually

being too refractory. This is a good example of why "burn on" is such a poor descriptive term.

That the adhering sand, shown in Fig. 2, is due to mechanical penetration can be seen by comparing the condition of the colloids in Figs. 1 and 2.

In Fig. 1 the colloids have fused completely and have drawn themselves around the unaltered silica grains, opening up voids for the metal to penetrate. The colloids shown in Fig. 2 have hardly been affected by the temperature of the molten iron.

#### CAUSES OF PENETRATION

Although the penetration in Fig. 2 is definitely due to mechanical penetration, the cause of this penetration cannot be proved by a simple microscopic study. Mechanical penetration can be due to too large grain size, soft ramming, or veining or cracking of the sand surface in contact with the metal, due to dimensional instability. This part of the investigation must be done by someone in the plant itself and cannot be done at another laboratory located miles away.

Figure 3 shows another example of sand adhering to an iron casting. The very large voids between the silica grains are completely filled with iron. Penetration in this case probably is due to soft ramming. At least it would be true for steel.

If the graphite flakes in Fig. 3 are neglected, the penetration in this sample is indistinguishable from that in Fig. 4, penetration into a steel sand that was proved to be due to soft ramming.

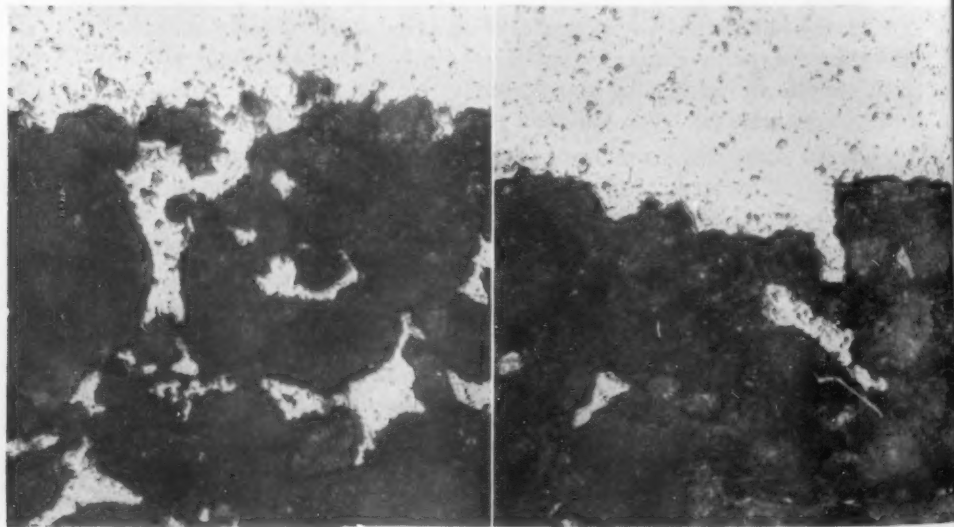


FIG. 1—LEFT—IRON PENETRATION DUE TO FUSION. VERTICAL ILLUMINATION. ( $\times 25$ ). FIG. 2—RIGHT—MECHANICAL PENETRATION OF IRON. VERTICAL ILLUMINATION. ( $\times 25$ ).



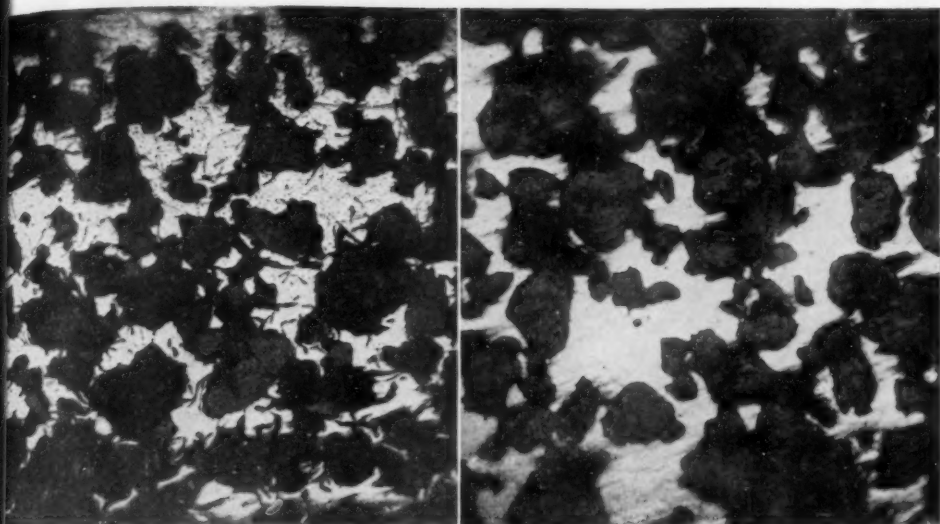


FIG. 3—LEFT—PENETRATION OF IRON INTO SAND, DUE PROBABLY TO SOFT RAMMING. VERTICAL ILLUMINATION. ( $\times 25$ ). FIG. 4—RIGHT—PENETRATION OF STEEL INTO SAND, PROVED TO BE DUE TO SOFT RAMMING. VERTICAL ILLUMINATION. ( $\times 25$ ).

Figure 5 shows a case of adhering sand on an iron casting, due to veining or dimensional instability. A number of foundrymen have confused this type of penetration with uniform penetration. It is important to distinguish these two types of penetration, as the mode of attack for their elimination is entirely different.

Note in this photomicrograph (Fig. 5) the continuous vein of iron at the left with a dense unpenetrated sand mass to the right. This condition is much plainer under visual examination than when photographed.

#### SIMPLE VISUAL EXAMINATION

No elaborate sample preparation is required for visual examination. All that is necessary is that the metal with the sand adhering to it, or the sand metal mixture, be ground on a fairly fine wheel. The metal stands out brilliantly from the dark sand mass and the mode of penetration is unmistakable to the observer.

Veining seems to be at least partially dependent on the relation between the pouring temperature of the metal and the "B" sintering point of the sand. A trace of fusion at the sand metal interface seems to act as a cushion or, perhaps, more like a glue and holds the sand together until the metal forms a solidified skin.

This is borne out in steel practice by the use of iron oxide, a compound that lowers the "B" sintering point slightly as well as increases the hot strength. It may be that in iron and non-ferrous practice a stronger flux would be bene-

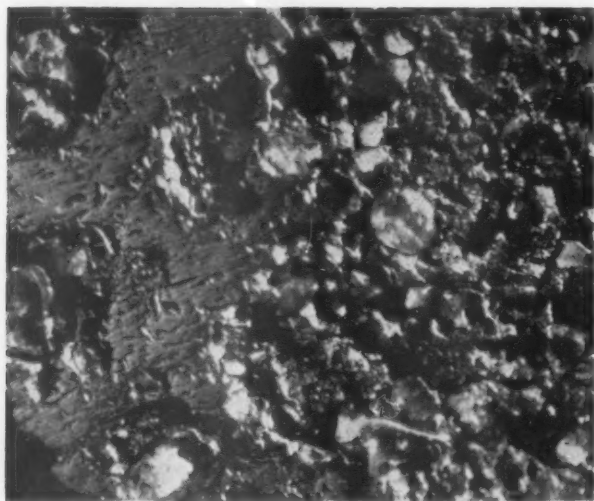


FIG. 5—PENETRATION DUE TO VEINING. COMBINATION, VERTICAL AND OBLIQUE ILLUMINATION. ( $\times 25$ ).

ficial. It is significant that veining is more prevalent on iron and non-ferrous castings than on steel castings, with their much higher temperatures at the sand metal interface.

#### SAMPLES REQUESTED

This report is submitted by the committee primarily to promote thought and discussion. It should be emphasized that a number of theories, especially regarding the mechanism of veining, require experimental confirmation. The committee is very anxious to receive samples of adhering sand, especially those that seem to be due to fusion without penetration, and samples of veining. The samples need not be large, one-half sq. in. of surface is sufficient. They can be sent to any member of the committee, or to the national office of the American Foundrymen's Association.

#### SUBCOMMITTEE ON SINTERING TEST

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# Thermosetting Plastic Core Binders for Ferrous and Non-Ferrous Metals

BY WILLIAM C. MORGAN\*, DETROIT, MICH.

## Abstract

*In this paper will be discussed types of thermosetting plastic core binders and their related factors in ferrous and non-ferrous metals; the relation of these binders to casting quality and the characteristics of the binders in reaction with sand and ingredients in the core sand formula. We will discuss their workability in the core room, including baking, collapsibility, gas and retained strength of the core. We will also deal with the procedure and results of experiments conducted to determine requirements of such binders in several foundries.*

1. Our interest in thermosetting plastics for core binders began some 3 years ago when, after several years of contact with the foundries, we concluded that many desirable features were not being realized from the present core binders in general. These desirable factors were probably more clearly realized with the advent of mass production of aluminum and magnesium castings. We realized that improvements could be made to reduce blows from gas, metal oxidation, cracked castings, and in knock-out qualities. If these problems were to be overcome, it was apparent that an improvement in core binders would materially aid the non-ferrous foundry industry and the war effort.

2. In our development of thermosetting plastic core binders, we soon recognized the fact that plastics in their neat form did not constitute the perfect core binder, such as so many foundries would like to have. Their principal disadvantages were odor, stickiness in the core box, storage life and critical baking temperature.

## CORE BINDER CHARACTERISTICS

3. The characteristics which would produce a more desirable core binder and which would approach the foundryman's idea of a perfect core binder were chosen as follows:

- (1) More rapid collapsibility.
- (2) Low retained strength.
- (3) Ease of shake-out.
- (4) Low gas content.
- (5) Workability in the core box.

\*Foundry Engineer, E. F. Houghton & Co.

NOTE: This paper was presented at a Sand Shop Course Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 25, 1944.

- (6) The core binder should work with low moisture content.
- (7) Reduce the amount of certain ingredients in the core mix.
- (8) High hot strength for ferrous and some non-ferrous metals.
- (9) Resist metal penetration.
- (10) Produce a protective atmosphere.
- (11) Ease of mixing and thoroughness of distribution in the core sand.
- (12) Reduce the number of core sand mixtures in the core room.

4. While these factors may not represent all the desirable factors of a core binder, we find that the variation in practice between foundries offers serious problems in producing a perfect core binder. Such problems as inadequate mixing equipment, limited oven capacity, type of sand, conditions of sand as received and the handling of baked cores are peculiar to the individual foundry.

#### *Classification*

5. In the following outline are classified the various binders currently used in volume in core sand:

- (1) Oil binders to produce baked strength.
  - a Mineral resin oils which partially polymerize on heating to gain their strength.
  - b Vegetable oils which gain their strength by combination with oxygen on heating.
  - c Marine animal oils.
- (2) Cereal binders for green strength.
  - a Gelatinized starches.
  - b Dextrine.
  - c Gelatinized corn flour.
- (3) Bentonites for green strength.
  - a Western.
  - b Southern.
- (4) Plastic core binders which entirely or partially replace types 1, 2 and 3.
  - a Minerals in combination with organic materials and synthetic resins.

While this outline does not include all materials used in binding core sand in the foundry industry, it serves to relate the characteristics of the various binders used in our development.

6. The aim of this paper is to bring up to date the work that has been carried on in various non-ferrous foundries, and to introduce the advantages of thermosetting plastics for ferrous foundries. Since we met last year, several magnesium foundries have adopted plastic core binders to the extent of 80 per cent of their binder requirements. Several aluminum foundries have shown interest, and some have adopted this type of binder to the extent of 50 per cent of their binder requirements. In fact, many castings are now being produced with the aid of plastic-bonded cores where it was not economical to produce them with oil and cereal binders because of excessive scrap loss.

7. In our development we realized a desire to produce binders which would afford high tensile strengths at low moistures, so as to give workability in the

core box comparable to oil-sand mixtures. Binders have been developed for the white metals and ferrous applications, as well as for brass and bronze.

8. So that we may more thoroughly understand the binding action of thermosetting plastics in sand, let us consider the chemical action involved. Naturally, anyone using resins desires to know how long the product containing resin should be cured under heat, and the temperature required to properly set the plastic.

### *Polymerization*

9. The term "cure" is commonly used, but a more correct term is polymerization. Phenol and urea-formaldehyde plastics polymerize to develop a long-chain product, in changing from soluble-fusible form to the final insoluble-infusible stage. For most commercial uses, particularly with molding compounds, the product is considered sufficiently cured when the compound containing resin has passed the blistering stage and is quite rigid while still hot. In the reaction of liquid plastics water is split off, which is referred to as condensation polymerization. Heat accelerates polymerization. In slightly acid or neutral conditions, the reaction progresses at a much slower rate, which makes possible the use of resins as sand binders. A common test to determine when this stage has been reached is to soak a baked core section in acetone for at least 10 min., or to rub it with a clean cloth soaked in acetone. If there is no discoloration or tendency to stickiness, the resin may be considered as substantially cured.

10. By taking advantage of this simple test, we are now in a better position than ever to determine when the cores are thoroughly baked. Because of the type of reaction involved, as previously mentioned, a more stable end point is reached in baking than in the case of oils and cereal binders, whose reactions are largely oxidization, and which continue at an accelerated rate as long as heat is applied. However, there are exceptions to this in the case of mineral polymer oils, which gain some of their strength through polymerization.

### *Core Baking Temperatures*

11. At this point it is in order to mention that the optimum baking temperature for thermosetting plastic core binders for white metals is 325° F., and for thermosetting binders for ferrous metals and brass is 450° F.

12. In addition to the advantage of determining when a core is thoroughly baked, there is another important advantage in the stability of reaction. When the resin has polymerized and heating continues, there is, of course, no further gain in strength and only a moderate loss. However, oxidation of the cereal continues with heating, which results in the "burning out" of a gas-forming product. Since cereals are ordinarily used to produce green strength properties, their purpose is served when a green core has started to bake. However, it is true that cereals produce dry strength, but this strength can be sacrificed to some extent to eliminate gas.

*"Curing"*

13. The speed at which a particular plastic cures is primarily dependent on the temperature used. The law of chemical reactions applies to plastics to a considerable extent. "For every 10° C. rise in temperature, the speed of reaction approximately doubles." The following example illustrates this:

A film containing 1.4 to 1.8 mg. per sq. in. of resin was spread on tin plate and baked in a circulating oven until the resin films were acetone proof.

The time necessary for such cure decreased greatly with increased temperatures, as follows:

300° F., 20 Min.

350° F., 5 Min.

400° F., 2 Min.

14. Since a certain number of heat units must be transferred to cure a given weight of plastic, it naturally follows that as the weight of plastic being cured is increased, a longer time must be allowed for the transfer of the greater quantity of heat units required. A section  $\frac{1}{8}$ -in. thick might require 5 min., and a section  $\frac{1}{2}$ -in. thick 20 min. Likewise, such additions as cereal and water to a core sand and the mass of the core must be taken into consideration in determining the heat units required.

*Gas Dissipation*

15. While it has been found that a standard tensile core specimen, when bonded with thermosetting plastics for white metals, will reach its peak strength in approximately 20 min. at 325° F. as compared with an oil-bonded specimen in 90 min., it is probably advisable to spend some of the time saved to dissipate gas by further baking. Many foundries have experienced a loss of core strength in cores which have been stored. This is attributed to moisture absorption from the atmosphere by the cereal which has not been burned out; hence we have another excellent reason why continued baking beyond the curing period of the plastic is essential. Of particular advantage is the fact that water-soluble plastics, when cured, become water insoluble and have a tendency to moisture proof a portion of other materials present which are water absorbent.

**STEEL FOUNDRY PRACTICE**

16. Table 1 and Fig. 1 illustrate a comparison between a compounded phenolic-formaldehyde core binder and raw linseed oil, which binders were evaluated for steel foundry practice.

17. Casual observation of the results shown in Table 1 would not seem to indicate a large reduction in gas content. However, it must be borne in mind that the mixture containing the phenolic plastic also contained 0.5 per cent of cereal binder, which ordinarily evolves 12 cc. of gas per gram. Under these conditions, it would be indicated that the actual gas content was probably much lower.

18. The values shown for collapsibility would indicate that shake-out is



Table 1

COMPARISON OF CORE PROPERTIES—THERMOSETTING PLASTIC CORE BINDERS  
AND RAW LINSEED OIL BONDED

Core Composition	Binder	
	Compounded Plastic Binders for Ferrous Metals and Brass	Raw Linseed Oil
A.F.A. Standard sand, grams	2000	2000
Cereal binder, grams	10	
Core binder, ratio by weight	1:40	1:75
Water, per cent	4.0	4.0
<i>Core Properties</i>		
Tensile Strength, psi., baked*		
30 min.	330	
45 min.	367.5	235
60 min.	355	245
90 min.	320	220
120 min.		170
Loss in strength on 100 per cent overbaking, per cent	13	31
Contact hardness, 60 min.	98	94
Green compression strength, psi.	0.3	0.2
Dry permeability	243	205
Collapsibility, 100-lb. load at 2500° F., sec.	43	26
Retained strength, core heated to 1500° F., for 5 min. and cooled to room temperature	42.7	36.4
Core gas, cc/gm at 2500° F.	16.5	20

\*All cores were baked at 450° F.

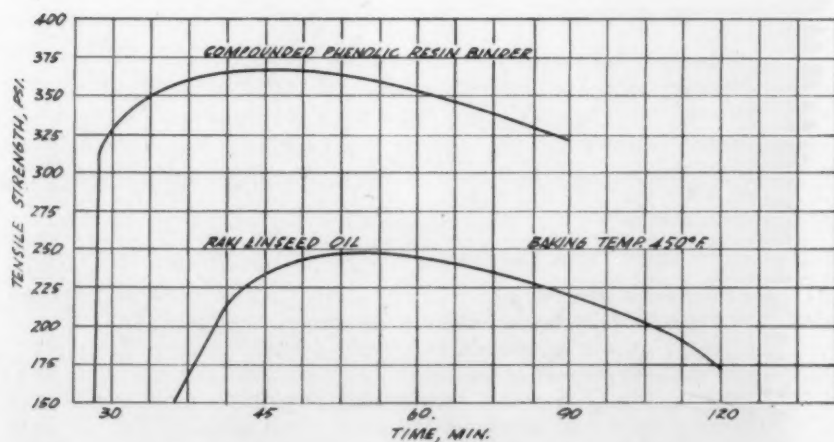


FIG. 1.—TENSILE STRENGTH CURVES OF A THERMOSETTING PLASTIC CORE BINDER VERSUS A RAW LINSEED OIL BINDER BAKED AT 450° F.

difficult. However, this is not actually true since it is necessary to differentiate between collapsibility and retained strength, which latter characteristic is the measure of shake-out.

19. The decomposition point of the bond of a plastic-type core binder is nearer its curing temperature than in the case of an oil binder, which continues to give off products of distillation as heat is applied. This accounts for the value of polymerization, which reaction takes place in the curing of plastics.

20. These results were confirmed by production tests in a large-production steel foundry, where 2 in. of molten steel surrounded a 1-in. dia. core with a total weight of 1800 lb. of metal per mold, poured at a temperature of 2950° F. Practically all of the weight of metal flows past four of the cores. The castings were observed in knock-out and showed a marked reduction of "burn in." Likewise, knock-out time was reduced from 30 min. to 5 min.

#### MAGNESIUM AND ALUMINUM FOUNDRY PRACTICE

21. Tables 2 and 3 illustrate a comparison between a compounded thermo-

**Table 2**

COMPARISON OF CORE PROPERTIES—THERMOSETTING PLASTIC CORE BINDERS  
AND COMPOUNDED LINSEED OIL BONDED

Core Composition	Binder	
	Compounded Plastic Binders for White Metals	Compounded Linseed Oil
Silica sand, A.F.A. 60, grams	2000	2000
Binder, cc	25	26.7
Water, per cent	4.0	4.0
Cereal binder, grams	10	
<i>Core Properties</i>		
Tensile Strength, psi., baked*		
20 min.	175	
30 min.	186	
45 min.	209	167
60 min.		226
90 min.		223
Hardness, 30 min.		
Contact	95	92
Drag	89	85
Green compression strength, psi.	1.0	0.5
Retained strength (core heated at 800° F. for 5 min., cooled in desiccator), lb.	28	218
Retained strength, per cent of original	1.5	96.5
Core gas, 4-gm. sample heated at 2500° F., cc	11.75	15.00
Collapsibility, 50-lb. load at 1200° F., min.	1.50	2.80
	(baked 30 min.)	(baked 90 min.)

\*All cores were baked at 325° F.

**Table 3**  
COMPARISON OF RATE OF GAS EVOLUTION IN CORE BINDERS

Time, min.	Gas Evolution			
	Compounded Thermosetting Plastic		Linseed Oil	
	Binders for White Metals			
	cu. cm.	per cent	cu. cm.	per cent
1/4	20	42.5	17	28.3
1/2	33	70.25	36	60.0
3/4	37	79.0	42	70.0
1	39	83.0	46	76.6
1 1/4	42	89.5	49	81.5
1 1/2	44	93.5	52	86.5
1 3/4	45	96.0	54	90.0
2	46	98	56	93.5
2 1/2	47	100	58	96.5
3	46		58	96.5
4	45		60	100.0
5	45		60	
6	45		60	
7	47		60	

setting plastic core binder for the white metals and a compounded linseed oil core binder which were evaluated for magnesium and aluminum foundry practice.

22. These results have been confirmed in magnesium foundries, and one specific example, with which many foundrymen are familiar, is the oil-sump casting, wherein complete collapsibility of the core is imperative not only to eliminate cracks but for sand removal. As a result, scrap from cracked castings has been reduced in one case from 30 per cent to less than 10 per cent, and shake-out time reduced from 8 min. to 1 1/2 min. Similar improvements have been noted in many other instances.

23. Aside from the fact that core gas evolution for the compounded thermosetting plastic core binders is appreciably lower, it is reducing in nature rather than oxidizing, and this is highly desirable. In many internal cores sulphur is completely eliminated, though it is still necessary in external cores.

#### CONCLUSIONS

24. From the data presented in the described tests, the following conclusions may be drawn:

(1) That the thermosetting plastics, when properly compounded and applied, have wide application as sand binders.

(2) The thermosetting plastics alone do not produce the ultimate requirements of a core binder.

(3) Each type of plastic has its merits for a particular metal being poured.

(4) The use of plastic-type core binders is unlimited, depending upon the attitude of the particular foundry.

(5) The progressive foundry will decide to use plastic-type core binders and expect certain opposition from the foundry personnel, which resistance, if properly handled, can be overcome and much improved core and casting quality will be realized.

(6) The heat units absorbed by the core from molten metal are definitely lower for aluminum and magnesium than for brass, bronze, cast iron and steel, hence the proper adaptation of various plastics is necessary to obtain the desired properties of collapsibility, "burn in" and ease of core removal from the casting.

(7) The amount of certain ingredients in the core mixture can be reduced, eliminating chances of error and thereby improving core quality.

(8) In the case of gray iron and steel, higher hot strengths and less gas will improve casting quality.

(9) Some foundries have experienced opposition from the odor of thermosetting plastics used in core binders. This can be overcome to a large extent by more thorough baking of the cores and the addition of urea crystals to the mixtures. Likewise, sticking in the core box has been troublesome. This problem has been minimized by the addition of one part of kerosene to 400 parts of core sand, and with the use of liquid partings.

(10) These disadvantages are pointed out to show that while there may be problems, they are not impossible of solution. We are on the threshold of a revolution in sand binders which, through the combined efforts of the foundrymen, will greatly improve the casting industry.

#### ACKNOWLEDGMENT

25. The author wishes to express appreciation to J. McElgin, Mgr. of the Metal Working Dept., E. F. Houghton & Co., and to his assistant, Mr. Harju; also to the H. W. Dietert Co., without whose efforts this work would not have been possible.

#### Bibliography

1. Dietert, H. W., "*Core Binders*," Lecture Course (1941-1942).
2. MODERN CORE PRACTICES AND THEORIES, American Foundrymen's Association, Chicago (1942).
3. Dietert, H. W., "*Controlling Properties of Cores*," Lecture Course (1941-1942).
4. Chamberlain, M. V., and Peters, A. T., "*Temperatures Developed in Sand Cores During the Casting of Magnesium Alloys*," TRANSACTIONS, American Foundrymen's Association, vol. 51, pp. 155-179 (1943).

## Hardenability and the Steel Casting†

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### Abstract

*Results of this investigation show that cast and forged steels of identical compositions, in the low and medium alloy range, have comparable hardenability when variations in grain size are considered. Increasing the normalizing temperature of the cast steels from 1700° F. (925° C.) to 2000° F. (1090° C.) prior to quenching from 1650° F. (900° C.) has little effect on the hardenability except as it alters the austenitic grain size. The agreement between calculated and experimentally determined hardenability, as measured by the end-quench bar, is exceptionally good for all of the steels studied except those containing more than small amounts of strong carbide forming elements. In steels containing appreciable amounts of chromium or molybdenum, the carbide forming elements covered in this study, a quenching temperature of 1650° F. (900° C.) is not high enough to ensure complete solution of all of the carbides, and as might be expected, the measured hardenability is considerably lower than that calculated from the chemical composition and austenitic grain size. Grossmann's hardenability factors were used throughout this study with the exception of the curve for molybdenum.*

### INTRODUCTION

1. Many steel foundrymen can recall the time when heat treatment of any kind for steel castings was viewed with distrust because such heat treatment was very apt to open cracks or reveal other defects which were not previously visible. Steel foundry practices have improved greatly since that time, and the overall integrity of modern steel castings has justified closer attention to heat treatment for the development of improved mechanical properties in the metal and thereby improved service performance of the castings. This attention has shifted progressively from no heat treatment at all through full annealing, normalizing and tempering, and recently to quenching and tempering.

2. Although it is recognized that quenching and tempering can not be applied to all steel castings because of mass or complicated design, many can be successfully heat treated in this manner. One purpose of this paper is to emphasize the metallurgical fact that complete hardening of a steel section produces better ductility after tempering to a given strength than full annealing

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or normalizing and tempering of the same steel to the same strength. Naturally, the steel must have the capacity for complete hardening in the quench which is to be used. This is the reason for the other and chief purpose of this paper, which is to show that the quantitative relationship between response to hardening and chemical composition and grain size, which has been developed for wrought steels, applies also to cast steels.

### STRENGTH AND DUCTILITY OF STEEL

3. By proper heat treatment steel can be made extremely hard and strong, it can be made relatively soft and weak, or it can be made to have intermediate degrees of hardness and strength within the particular limits imposed by composition, primarily the carbon content. High strength is desirable in engineering machine parts and structures, section modulus being duly considered, since mass can be reduced accordingly with resultant savings in material and elimination of dead weight. These points are extremely important when moving parts or mobility of an assembly are involved.

4. Strength is not the only requisite for most applications of steel. Ductility is also necessary so that unexpected overloads or unforeseen notch effects will not cause brittle failure. Unfortunately, the ductility of steel inherently decreases as its strength is raised so that, instead of designing for maximum strength which might be in excess of 200,000 psi., designers call for only a fraction of the strength obtainable so that the necessary ductility may be present.

5. Beyond the broad generality that as ductility is increased the tensile strength or hardness is decreased, it is accepted that other factors have a profound influence on this relationship. Nothing more than mention need be made of the fact that coarse grain structure, chain-like inclusions, porosity, or excessive hydrogen will cause lower ductility than that expected for a given strength. Assuming that these adverse conditions are minimized, there is still another factor which should be fully considered in attempting to develop the maximum ductility at any given strength. This factor is the microstructure, aside from grain size, which is developed by heat treatment.

6. For some time it has been known that forged steels show a much greater ductility at a given strength in the quenched and tempered condition than they do in either the normalized or annealed state<sup>1</sup>. Likewise, the best combination of strength and ductility is produced in cast steels by quenching and tempering treatments<sup>2</sup>.

### PHYSICAL PROPERTIES DEVELOPED BY QUENCHING AND TEMPERING

7. Table 1 illustrates the improved yield to tensile strength ratio, and the higher ductility at a given strength for plain carbon steels in the quenched and tempered condition. This enhancement of physical properties through quenching and tempering is not restricted to plain carbon steels, but is found in low

<sup>1</sup> Superior numbers refer to references at the end of the paper.



Table 1

## PHYSICAL PROPERTIES DEVELOPED BY INDICATED HEAT TREATMENTS

Properties	Quenched and Tempered	Normalized	Annealed
Tensile Strength, psi.	80,000	80,000	80,000
Yield Strength, psi.	65,000	48,000	43,000
Reduction of Area, per cent	65	50	45
Tensile Strength, psi.	100,000	100,000	100,000
Yield Strength, psi.	74,000	55,000	45,000
Reduction of Area, per cent	56	37	30
Tensile Strength, psi.	120,000	120,000	
Yield Strength, psi.	95,000	64,000	
Reduction of Area, per cent	50	26	

and medium alloy steels as well. These statements are made with the reservation that the size of section being considered has been hardened throughout.

8. The maximum physical properties derived from quenching and tempering are never realized in a partially hardened section. Figure 1 illustrates the so-called "mass effect" for two S.A.E. steels. In all cases the smaller section sizes yield superior physical properties. This trend can be analyzed much more conclusively than by merely designating it as a "mass effect." If a steel is of such a composition that, upon quenching, it will just harden throughout in a one-inch section, any section larger than one inch when similarly quenched will have an unhardened core or center consisting of pearlite and ferrite. Further increases in section size cause a decrease in the percentage of the section which is fully hardened, and thus further decrease the average physical properties.

9. The effect of increasing section size for a carbon-molybdenum steel quenched in oil, water and brine is shown in Fig. 2. Quite often special alloy-

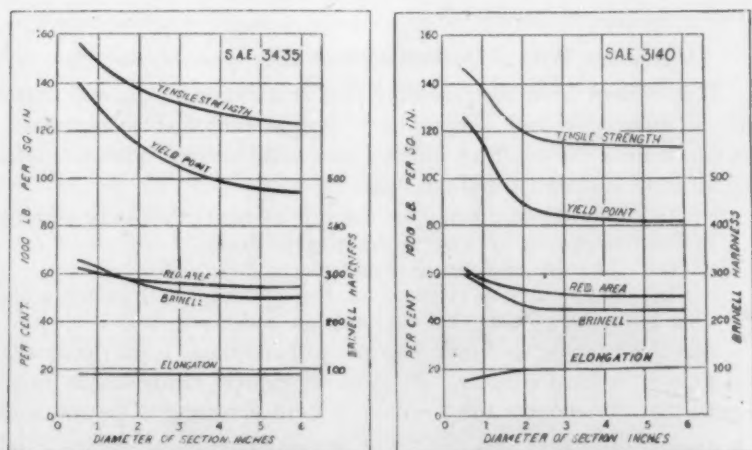


FIG. 1—"MASS EFFECT" FOR TWO S.A.E. STEELS, OIL QUENCHED AND TEMPERED AT 1000° F.

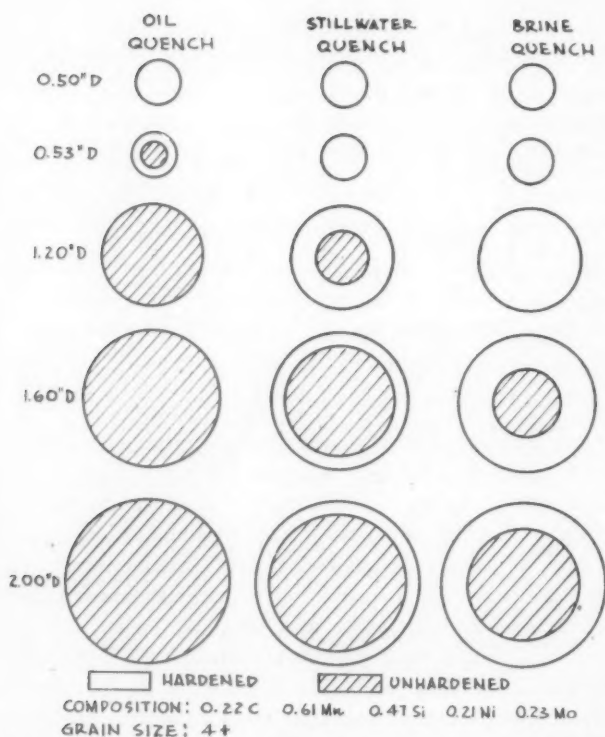


FIG. 2—EFFECT OF SIZE AND QUENCHING MEDIA ON THE DEPTH OF HARDENING OF A CARBON-MOLYBDENUM STEEL.

ing elements have been credited with greatly enhancing the strength of steels in the quenched and tempered condition, when actually they have merely increased the depth of hardening.

#### VARIABLES WHICH DETERMINE THE DEPTH OF HARDENING

10. It is evident from the foregoing that in order to obtain the maximum benefits of quenching and tempering, it is necessary first to determine the factors which limit the depth to which a steel will harden. Three such factors are particularly apparent from experience:

- (a) Severity of quench, or the rate at which heat can be removed from the casting by some quenching medium.
- (b) The size and shape of the piece.
- (c) The inherent response of the material to hardening due to the influence of chemical composition and grain size.

11. The third factor, inherent response to hardening, is that characteristic of steel known as hardenability. In order to express hardenability quantitatively, the first two factors must either be held constant or be measured in such a manner that they can become a significant part of the hardenability expression.

### *Severity of Quench*

12. The effect of severity of quench has been determined<sup>3</sup> and the index of the severity of quench ( $H$ ) may be expressed in terms of the diameter of round which will just harden through under the most severe quenching condition and the diameter of round which will just harden through under any other specific condition of quenching. A section may be considered hardened throughout when it has a microstructure of 50 per cent martensite at the center. This particular microstructure is a satisfactory index and has been selected primarily because of the ease with which it can be determined by fracture or etch tests.

13. The most severe possible quench is referred to as an "ideal quench" and is defined as that quench in which the external surface of the piece being cooled reaches the temperature of the quenching medium instantaneously. An "ideal quench" is impossible to achieve in practice, but it does serve as a convenient reference value.

### *Size and Shape of Piece*

14. The second factor, size and shape of the piece, can be eliminated as a variable by stating hardenability in terms of that size of round which will just harden through when quenched in a bath of some known quenching severity. Hardenability is usually expressed as "ideal critical diameter" ( $D_I$ ) which is, by definition, a round of a size that will just harden through under conditions of an ideal quench.

15. It might appear to anyone who is not thoroughly familiar with hardenability that the terms, "ideal quench" and "ideal critical diameter" ( $D_I$ ), are hypothetical and impractical since an ideal quench is impossible to attain in practice, and, therefore, it is impossible to measure an ideal critical diameter directly.

16. However, these concepts have served a very useful purpose since much of the working theory behind hardenability was developed from a mathematical analysis (this analysis involved the concept of the ideal quench) of heat flow in metals; moreover, they continue to serve a useful purpose because ideal critical diameter ( $D_I$ ) is the only unit of hardenability which, at the present time, can be quantitatively related to chemical composition and grain size. It is not necessary to know the development of  $D_I$  to determine it or to use it as a measure of hardenability. To find  $D_I$  it is necessary to know the critical diameter of the steel in question when it is hardened in a bath of some known severity of quench.

17. The severity of quench ( $H$ ) for any quenching bath can be determined experimentally<sup>3</sup>, and severity of quench values ( $H$ ) are published for common quenching media, i.e.,  $H$  for still water<sup>4</sup> is 0.9 to 1.0,  $H$  for still oil<sup>4</sup> is 0.25 to 0.30,  $H$  for still brine<sup>4</sup> is 2, etc. The critical diameter for any steel ( $D$ ), or size of round which will just harden through in a quench of some known

severity, also can be determined experimentally, and with these two known values,  $H$  and  $D$ , the ideal critical diameter ( $D_I$ ) can be read from one of the curves of Fig. 3. Likewise, if  $D_I$  is known,  $D$  can be determined in any quenching bath for which the severity of quench is known.

#### EXPERIMENTAL AND CALCULATED HARDENABILITY

18. It was stated in the preceding paragraph that the hardenability of a steel ( $D_I$ ) is a function of its chemical composition and grain size and, there-

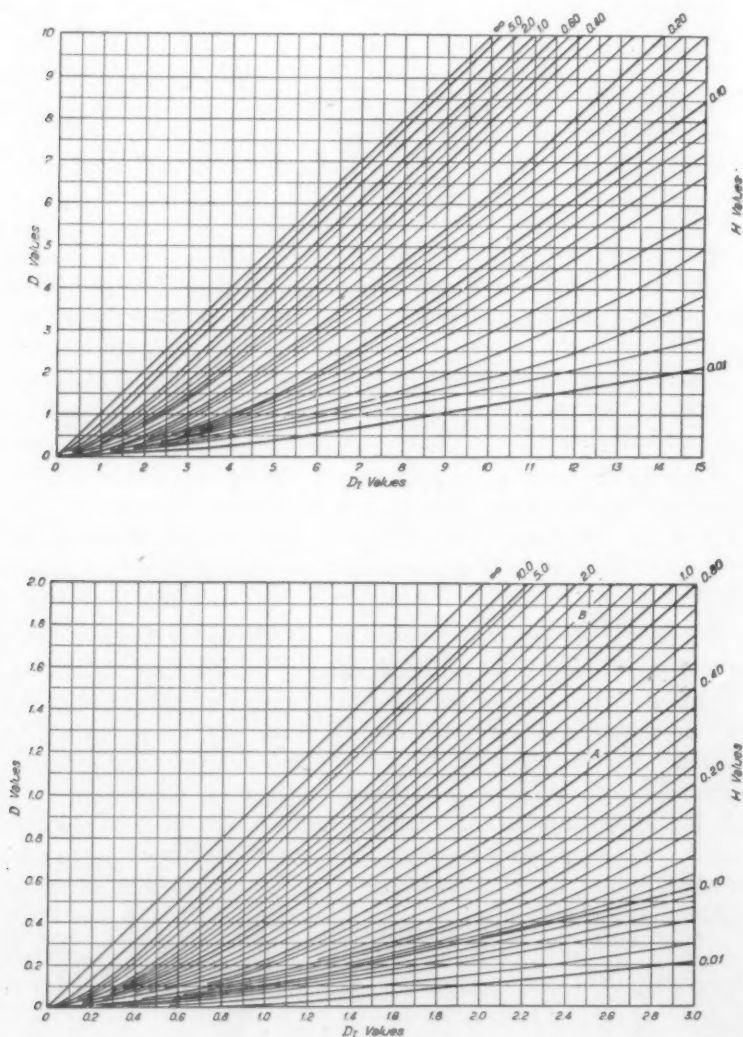


FIG. 3—TOP—RELATIONSHIP AMONG IDEAL CRITICAL SIZE  $D_I$ , ACTUAL CRITICAL SIZE  $D$ , AND SEVERITY OF QUENCH  $H$ . BOTTOM—SAME AS ABOVE BUT DIFFERENT SCALE.

fore, it should be possible to calculate  $D_I$  if the steel has been completely analyzed and if its grain size at the quenching temperature has been determined. A system of calculated hardenability has been developed for wrought steels but, before its application is considered for cast steels, it is desirable to review briefly some of the pertinent investigations in this field.

19. Since the practice of quenching and tempering has long been used for the treatment of tool steels, it is natural that the first work on hardenability was done on tool steels. Shepard<sup>5</sup> pioneered the work in this country, and his investigations led to the development of the "P-F" test for tool steels. This test consists of quenching a round specimen under carefully controlled conditions, breaking the bar, rating the fracture for appearance, grinding the fractured surface, etching and measuring the depth of penetration of hardening.

20. Shepard's work was the forerunner of numerous investigations concerning the hardening characteristics of constructional steels. Two particularly significant investigations, in which modifications of Shepard's method of quenching rounds were used, are those reported by Burns, Moore and Archer<sup>6</sup>, and by Grossmann, Asimow, and Urban<sup>3</sup>. Herein is the basis for the concepts of ideal quench and ideal critical diameter which have been discussed previously.

#### HARDENABILITY MEASUREMENT

21. Another important investigation which has had a profound effect upon present day hardenability measurement was reported by Jominy and Boegehold<sup>7</sup>. This work was done on carburizing steels, but the method of measurement, which has since been used so widely because of its relative convenience as compared to the quenching of rounds, was also found to be applicable to non-carburizing types of constructional steels. Its importance warrants a brief description of the test.

22. Jominy's hardenability test consists of simply end-quenching a bar of standard length and diameter from its proper hardening temperature with a controlled stream of water impinging on one end of the specimen, grinding opposite parallel flats along the longitudinal axis, and making hardness determinations at regularly spaced intervals along the ground portions of the bar. A plot of hardness versus distance from the quenched end yields the typical curve shown in Fig. 4.

23. To avoid the necessity for reproducing the entire curve when discussing the results of a Jominy test, it is conventional to state, as an index of hardenability, that distance from the quenched end at which the hardness drops to the value indicative of a microstructure of 50 per cent martensite. The reasons for choosing the point of 50 per cent martensite have been explained before in connection with its use in rounds. This index of hardenability is referred to as the Jominy distance. It was found possible to correlate Jominy distance with Grossmann's ideal critical diameter ( $D_I$ ).

24. It is to be noted that the investigations mentioned so far have been

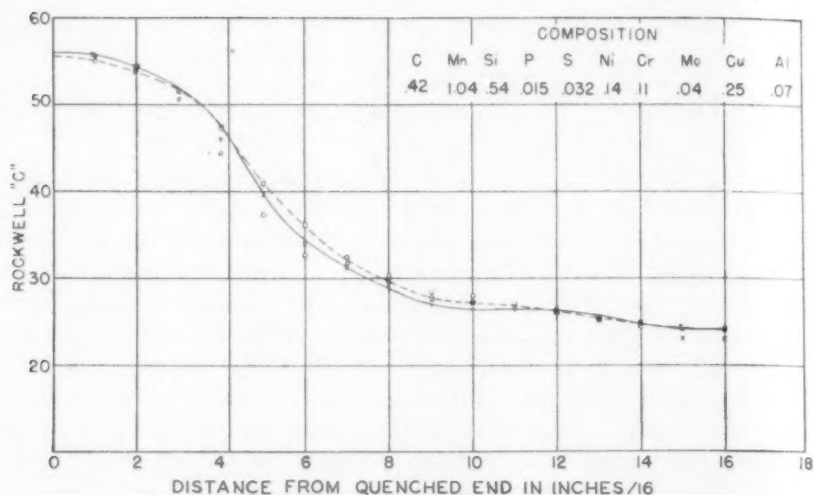


FIG. 4—TYPICAL END-QUENCH CURVE. ROCKWELL "C" HARDNESS PLOTTED AGAINST DISTANCE FROM QUENCHED END.

concerned primarily with the measurement of hardenability. Such information is extremely valuable. For example, if a certain machine part is made from a heat of steel having a measured  $D_I$  of 2.4 and it "quenches out" satisfactorily, another heat of steel having a  $D_I$  of 2.4 generally responds to similar quenching in a similar manner.

#### EFFECT OF ALLOYING ELEMENTS AND GRAIN SIZE

25. The useful aspects of measured hardenability have been greatly broadened by an understanding of the quantitative effect of the alloying elements and grain size on the hardenability of the steel. It is thus possible to predict closely the most economical or available steel for a given job. This important work on calculating hardenability from chemical composition and grain size was described in a paper by Grossmann<sup>4</sup>. Wrought steels were used for the development of his principle, which consists of establishing a base hardenability for carbon and grain size alone and determining independent multiplying factors for each of the additional alloying elements present.

26. This principle has been confirmed by the more recent investigations of Crafts and Lamont<sup>8</sup>, of Kramer, Hafner and Toleman<sup>9</sup> and of Comstock<sup>10</sup>. Although they substantiated the method, these investigators found certain differences in the numerical values of individual multiplying factors. These differences may possibly be attributed to the fact that more recent studies were carried out using the end-quench (Jominy) test to measure the hardenability and then converting the end-quench data to Grossmann's  $D_I$ , whereas Grossmann's work was carried out entirely on quenched rounds which gave values of  $D_I$  directly. This conversion was made by a calculated curve<sup>11</sup> which is believed to be slightly in error.



## EXPERIMENTAL WORK

27. Since the object of the work described herein was to determine if the hardenability of forged steels is the same as that of cast steels of the same compositions, it was necessary to make and split heats of steel to obtain cast specimens and blanks for forging other specimens.

28. Sixteen heats of steel of the compositions shown in Table 2 were used in this investigation. All were made in a 300-lb. coreless induction furnace and poured into green sand molds to produce castings of the size and shape shown in Fig. 5. The cast plates were fed by two over-sized blind risers and the 4-in. cubes were fed by open risers. A standard melting practice was followed which facilitated close composition control. Sheared S.A.E. 1015 steel was used as the melting stock and alloys were added as ferro-alloys or as commercial pure metals.

29. The cast plates were sectioned to obtain four specimen blanks, each being 1/4-in. square and 6-in. long. The 4-in. cubes were forged to 1 1/2-in. diameter bars. Three of the cast coupons from each heat were then normalized at 1700° F. (925° C.), 1850° F. (1010° C.) and 2000° F. (1090° C.), respectively. The forged bars were double normalized at 1850° F. (1010° C.). Normalizing cycles were so adjusted that all pieces were at temperatures for one hr. and 30 min. After normalizing, the coupons were machined to the standard type Jominy bar (Fig. 6).

30. All Jominy bars were heated in close fitting carbon blocks to 1650° F. (900° C.), held for an hour at temperature, and quenched in the jig shown in Fig. 7. Opposite parallel flats were then wet-ground to a depth of 0.10 in. This depth was selected because it yielded primarily the same hardness contours as those obtained by grinding to a depth of 0.015 in., Fig. 8, but it

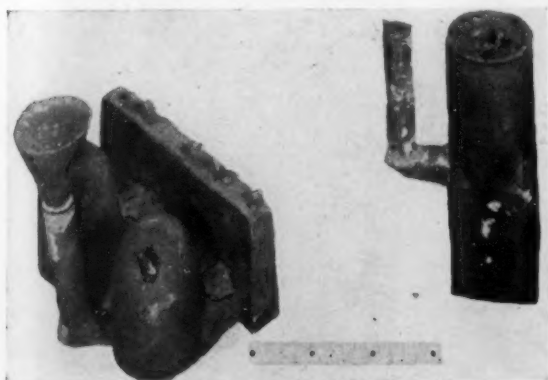


FIG. 5—ABOVE—TEST CASTINGS AS REMOVED FROM MOLDS.

FIG. 6—RIGHT—STANDARD JOMINY BAR. LEFT—AS PREPARED FOR QUENCHING. RIGHT—AS PREPARED FOR HARDNESS SURVEY.



Table 2  
HEAT COMPOSITIONS (PER CENT) AND ALLOY MULTIPLYING FACTORS

Heat	C	Mn	Si	P	S	Ni	Cr	Mo	Cu	Al	Boron
A	Composition	0.37	1.00	0.57	0.019	0.031	0.11	0.12	0.05	0.25	0.04
	Multiplying Factors		4.3	1.53	1.04	0.981	1.04	1.28	1.12	1.07	1.04
B	Composition	0.42	0.90	0.62	0.010	0.025	0.18	0.03	0.22	0.27	0.06
	Multiplying Factors		3.95	1.58	1.02	0.985	1.06	1.07	1.52	1.08	1.05
C	Composition	0.33	0.82	0.59	0.038	0.020	0.16	0.05	0.20	0.25	0.02
	Multiplying Factors		3.7	1.55	1.08	0.987	1.06	1.11	1.48	1.07	1.02
D	Composition	0.38	0.57	0.62	0.008	0.028	0.60	0.47	0.03	0.25	0.07
	Multiplying Factors		2.9	1.58	1.01	0.982	1.21	2.08	1.07	1.07	1.07
E	Composition	0.34	0.82	0.62	0.011	0.028	0.54	0.46	0.02	0.25	0.07
	Multiplying Factors		3.70	1.58	1.023	0.982	1.19	2.05	1.05	1.07	1.07
G	Composition	0.22	0.53	0.45	0.010	0.016	0.55	0.48	0.40	0.27	0.15
	Multiplying Factors		2.75	1.415	1.02	0.990	1.19	2.10	1.96	1.07	1.14
H	Composition	0.19	0.53	0.47	0.010	0.017	0.23	0.75	0.24	0.28	0.07
	Multiplying Factors		2.75	1.44	1.02	0.989	1.08	2.72	1.57	1.08	1.07
I	Composition	0.24	0.85	0.45	0.010	0.022	0.21	0.75	0.23	0.28	0.07
	Multiplying Factors		3.80	1.415	1.02	0.987	1.07	2.72	1.55	1.08	1.07
J	Composition	0.38	0.56	0.52	0.010	0.022	0.21	0.28	0.25	0.29	0.05
	Multiplying Factors		2.85	1.485	1.02	0.987	1.07	1.65	1.60	1.08	1.05
K	Composition	0.40	0.93	0.47	0.012	0.023	0.17	0.065	0.41	0.28	0.07
	Multiplying Factors		4.05	1.44	1.025	0.986	1.06	1.14	1.98	1.07	1.07
L	Composition	0.22	0.54	0.41	0.004	0.019	0.15	0.40	0.39	0.27	0.03
	Multiplying Factors		2.77	1.38	1.01	0.988	1.05	1.92	1.94	1.07	1.03
M	Composition	0.32	0.61	0.47	0.007	0.022	0.21	0.07	0.23	0.29	0.01
	Multiplying Factors		3.00	1.44	1.01	0.987	1.07	1.16	1.55	1.08	—
O	Composition	0.26	0.41	0.31	0.019	0.031	0.14	0.23	0.23	0.25	0.08
	Multiplying Factors		2.35	1.29	1.04	0.98	1.05	1.53	1.55	1.07	1.075
P	Composition	0.31	1.55	0.51	0.022	0.031	0.12	0.12	0.06	0.26	0.07
	Multiplying Factors		6.1	1.48	1.05	0.98	1.04	1.28	1.15	1.07	1.07
N	Composition	0.41	0.55	0.56	0.010	0.028	0.64	0.41	0.02	0.27	0.05
	Multiplying Factors		2.80	1.53	1.02	0.983	1.23	1.94	1.05	1.07	1.05
S	Composition	0.45	0.73	0.58	0.009	0.028	0.23	0.01	0.02	0.29	0.07
	Multiplying Factors		3.40	1.54	1.01	0.983	1.08	1.02	1.05	1.07	1.07

\*Per cent added.



FIG. 7—QUENCHING JIG USED IN TESTS.

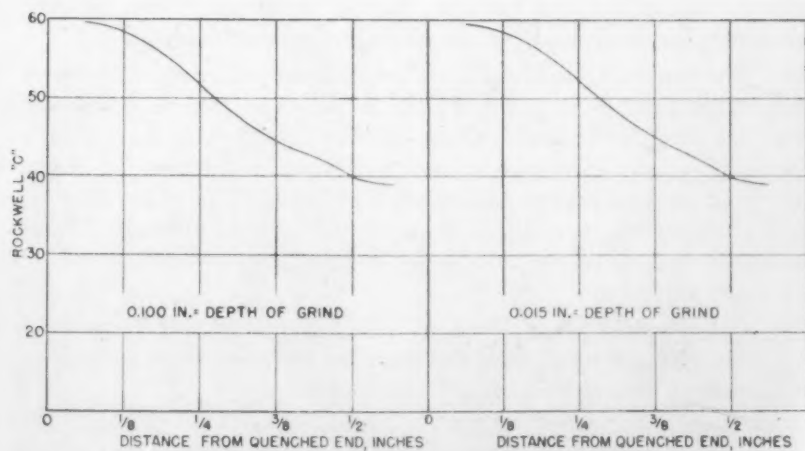


FIG. 8—EFFECT OF DEPTH OF GRIND ON THE JOMINY CURVE.

eliminated erratic readings due to uncontrolled surface effects and thus ensured good reproducibility of the data.

31. Rockwell "C" hardness surveys were made with a Rockwell hardness tester. The jig shown in Fig. 9 was used for rapid and accurate spacing of the hardness indents. The accuracy of the positioning jig is plus or minus 0.004 in., and the hardness determinations are believed to be accurate to plus or minus one Rockwell "C" number.

32. The Jominy bars were electrolytically polished and the grain size of each bar was determined by projecting an image of the etched surface on a screen and making a visual comparison with the standard A.S.T.M. grain size chart. In several cases, photomicrographs were taken and actual counts made. Comparison showed the estimated grain size to be accurate within plus or minus one-half of an A.S.T.M. grain size number.

33. Samples for chemical analysis of each heat were obtained from the portion of the plate remaining after the necessary Jominy bar blanks had been removed, and the steels were analyzed for all elements which were apparent from spectrographic analysis and which are known to affect hardenability.

#### *Data Obtained*

34. The chemical compositions of the 16 heats of steel used in this investigation are given in Table 2.

35. Jominy curves were plotted for all bars from the hardness data. Using the relationship between carbon content and hardness of 50 per cent martensite shown in Fig. 10, Jominy distances were read from the Jominy curves and were corrected to a quenching temperature of 1600° F. (870° C.) by employing a factor taken from the curve in Fig. 11. This curve was taken from the work of Jackson and Christenson<sup>12</sup> which showed that if quantitative hardenability is to be determined from the Jominy curve, the effect of quenching temperature must be considered from a purely thermal standpoint.

36. The corrected Jominy distance values were converted to  $D_I$  values by means of the lower curve of Fig. 12 and are listed in Table 3. It should be noted that this lower curve does not coincide exactly with that taken from Grossmann's paper. The revised curve was based on hardness measurements rather than upon calculated half-temperature times. It is believed to represent the relationship more closely than the other curve, although differences between the two curves are not enough to change the overall aspects of the work materially.

37. Calculated  $D_I$  values, listed in Table 3, for all Jominy bars were computed from chemical composition and grain size by Grossmann's method, which is illustrated by the following sample calculation:

$D_I$  for carbon and grain size is read from Fig. 13, and the individual multiplying factors for the corresponding amount of each alloy present are read from the curves of Figs. 14 and 15. The product of



FIG. 9—SPACING JIG FOR USE WITH ROCKWELL HARDNESS TESTER.

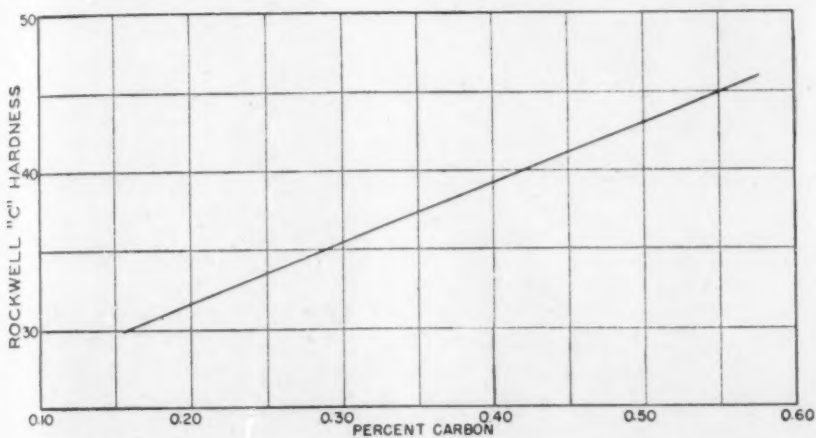


FIG. 10—MARTENSITE HARDNESS (50 PER CENT) PLOTTED AGAINST CARBON CONTENT.

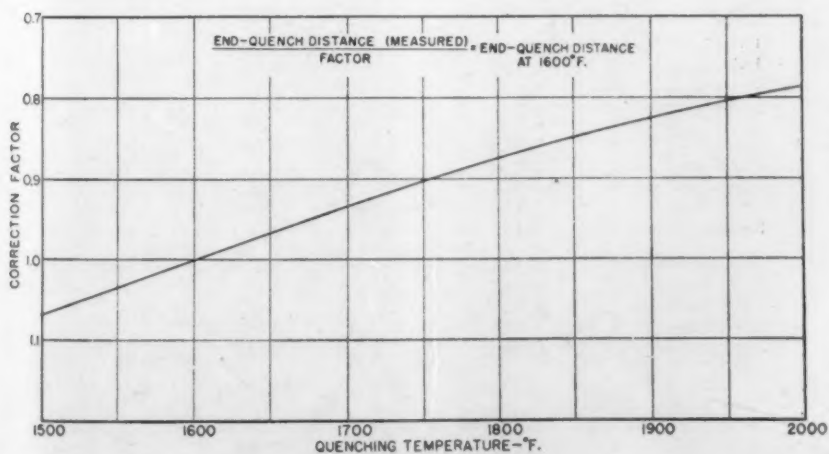


FIG. 11—CURVE FOR CORRECTION OF DISTANCE ALONG END-QUENCH HARDENABILITY BAR FOR QUENCHING TEMPERATURE.

Table 3

## HARDENABILITY DATA

Heat	Prior Treatment	Grain Size No.	Dt Carbon and Grain Size	Jominy Distance Measured/16	Jominy Distance Measured at 1600° F./16	Meas. Dt	Calc.
A	As Cast	8	0.185	4.7	4.85	2.15	2.10
	†1700 Soak	8	0.185	4.7	4.85	2.15	2.10
	1850 Soak	8	0.185	4.7	4.85	2.15	2.10
	2000 Soak	7	0.201	5.3	5.46	2.30	2.28
	Forged	8	0.185	4.7	4.85	2.15	2.10
B	As Cast	6½	0.225	7.1	7.33	2.70	2.73
	1700 Soak	8	0.197	6.1	6.30	2.48	2.40
	1850 Soak	7½	0.206	6.3	6.50	2.52	2.50
	2000 Soak	6½	0.225	7.1	7.33	2.70	2.73
	Forged	6½	0.225	7.1	7.33	2.70	2.73
C	As Cast	6½	0.200	5.9	6.10	2.44	2.38
	1700 Soak	6	0.210	6.1	6.30	2.48	2.50
	1850 Soak	5	0.228	7.2	7.43	2.72	2.72
	2000 Soak	4½	0.240	7.6	7.84	2.80	2.85
	Forged	5	0.228	7.4	7.64	2.75	2.72
D	As Cast	9	0.173	5.2	5.36	2.28	2.44
	1700 Soak	9	0.173	4.8	4.95	2.18	2.44
	1850 Soak	9	0.173	5.0	5.15	2.23	2.44
	2000 Soak	8½	0.180	5.5	5.67	2.34	2.54
	Forged	9	0.173	6.1	6.30	2.48	2.44
E	As Cast	8	0.177	9.0	9.30	3.10	3.12
	1700 Soak	9	0.162	7.2	7.43	2.72	2.84
	1850 Soak	9	0.162	8.0	8.25	2.88	2.84
	2000 Soak	8½	0.170	8.3	8.56	3.00	3.00
	Forged	10	0.149	6.5	6.70	2.56	2.63
G	As Cast	12	0.101	5.6	5.87	2.40	2.38
	1700 Soak	12½	0.097	5.3	5.46	2.31	2.28
	1850 Soak	12	0.101	5.6	5.87	2.40	2.38
	2000 Soak	12	0.101	5.6	5.87	2.40	2.38
	Forged	12½	0.097	5.3	5.46	2.31	2.28
H	As Cast	9½	0.117	5.2	5.36	2.28	2.50
	1700 Soak	9½	0.117	5.2	5.36	2.28	2.50
	1850 Soak	9	0.122	5.2	5.36	2.28	2.60
	2000 Soak	9	0.122	5.2	5.36	2.28	2.60
I	As Cast	9½	0.130	8.3	8.56	2.95	3.64
	1700 Soak	9½	0.130	7.4	7.64	2.76	3.64
	1850 Soak	9	0.137	8.8	9.06	3.05	3.84
	2000 Soak	9	0.137	8.8	9.06	3.05	3.84
	Forged	9	0.137	8.8	9.06	3.05	3.84
J	As Cast	8	0.188	6.2	6.40	2.50	2.56
	1700 Soak	8	0.188	5.8	5.97	2.40	2.56
	1850 Soak	7	0.205	6.8	7.01	2.63	2.83
	2000 Soak	6	0.224	6.3	6.50	2.52	3.06
	Forged	8½	0.180	5.4	5.57	2.32	2.47
K	As Cast	7½	0.201	9.8	10.10	3.25	3.25
	1700 Soak	7½	0.201	9.8	10.10	3.25	3.25
	1850 Soak	7½	0.201	10.0	10.30	3.29	3.25
	2000 Soak	6½	0.220	11.6	11.98	3.58	3.56
	Forged	8	0.194	9.2	9.50	3.14	3.14

†Temperatures in ° F.



Table 3 (Continued)  
HARDENABILITY DATA

Heat	Prior Treatment	Grain Size No.	$D_1$ Carbon and Grain Size	Jominy Distance Measured/16	Jominy Distance Measured at 1600° F./16	$D_1$	
						Meas.	Calc.
L	As Cast	8	0.143	4.7	4.85	2.15	2.15
	1700 Soak	8	0.143	4.9	5.05	2.20	2.15
	1850 Soak	8	0.143	4.9	5.05	2.20	2.15
	2000 Soak	7½	0.150	5.2	5.36	2.28	2.27
	Forged	7½	0.150	5.1	5.25	2.25	2.27
M	As Cast	3½	0.211	3.8	3.92	1.92	1.90
	1700 Soak	4	0.202	3.6	3.72	1.87	1.83
	1850 Soak	3½	0.211	3.8	3.92	1.92	1.90
	2000 Soak	3½	0.211	3.8	3.92	1.92	1.90
	Forged	3	0.222	4.4	4.53	2.07	2.02
O	As Cast	6½	0.177	2.7	2.78	1.60	1.57
	1700 Soak	8	0.155	2.1	2.17	1.40	1.38
	1850 Soak	7½	0.162	2.3	2.37	1.48	1.44
	2000 Soak	7	0.170	2.5	2.58	1.55	1.51
	Forged	7	0.170	2.5	2.58	1.55	1.51
P	As Cast	10	0.142	5.4	5.57	2.32	2.32
	1700 Soak	8½	0.162	7.0	7.22	2.64	2.64
	1850 Soak	8½	0.162	6.0	6.20	2.46	2.64
	2000 Soak	8	0.169	6.0	6.20	2.46	2.75
	Forged	10	0.142	5.5	5.67	2.35	2.32
*N	As Cast	7	0.212	8.7	8.97	3.02	3.62
	1700 Soak	7	0.212	10.0	10.30	3.29	3.62
	1850 Soak	6	0.231	12.4	12.75	3.71	3.94
	2000 Soak	5	0.252	13.0	13.40	3.80	4.30
	Forged	8	0.195	7.6	7.85	2.80	3.33
**S	As Cast	4½	0.275	6.9	7.10	2.65	2.68
	1700 Soak	4½	0.275	7.1	7.30	2.70	2.68
	1850 Soak	4½	0.275	7.0	7.20	2.67	2.68
	2000 Soak	4	0.290	7.5	7.74	2.78	2.82
	Forged	4½	0.275	7.1	7.30	2.70	2.68

\*Fouled hot.  
\*\*Poured cold (skull).

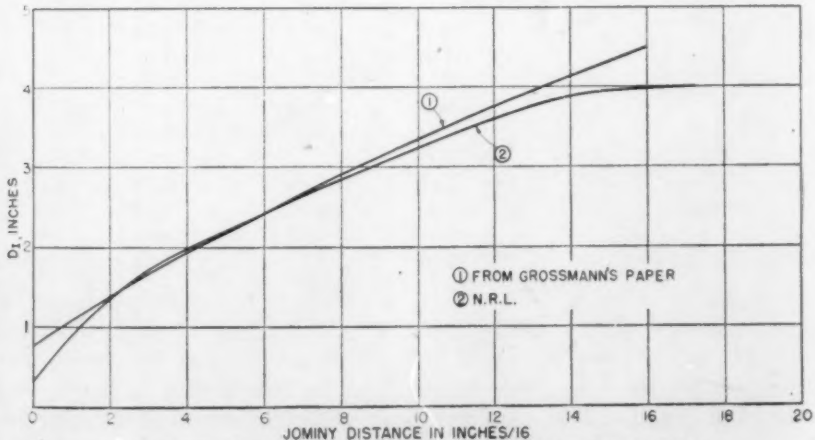


FIG. 12—CURVE FOR CONVERSION OF JOMINY DISTANCE VALUES TO  $D_1$  VALUES.

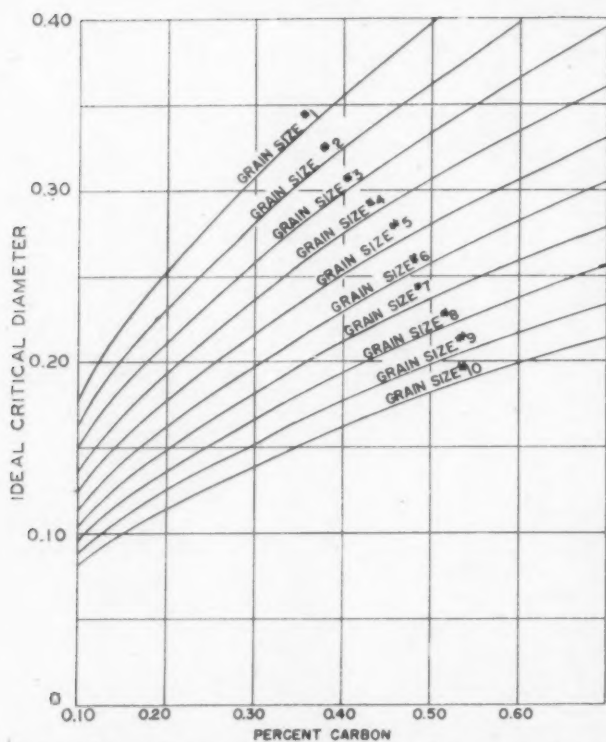


FIG. 13—IDEAL CRITICAL DIAMETERS FOR VARIOUS CARBON CONTENTS AND GRAIN SIZES.

$D_I$  for carbon and grain size and the alloy factors is equal to  $D_I$  for the steel in question.

Elements	Composition, per cent	Multiplying Factor
C	0.37	0.201*
Mn	1.00	4.3
Si	0.57	1.53
P	0.019	1.04
S	0.031	0.981
Ni	0.11	1.04
Cr	0.12	1.28
Mo	0.05	1.12
Cu	0.25	1.07
Al	0.04	1.04

\* $D_I$  for grain size of A.S.T.M. No. 7.

Product of factors = 2.28  
 $D_I = 2.28$  inches

38. The base hardenabilities for carbon and grain size of the Jominy bars are individually listed in Table 3, and the alloy multiplying factors for the quantities of elements other than carbon which were present in the steels studied are given in Table 2. Grossmann's hardenability factors were used through-

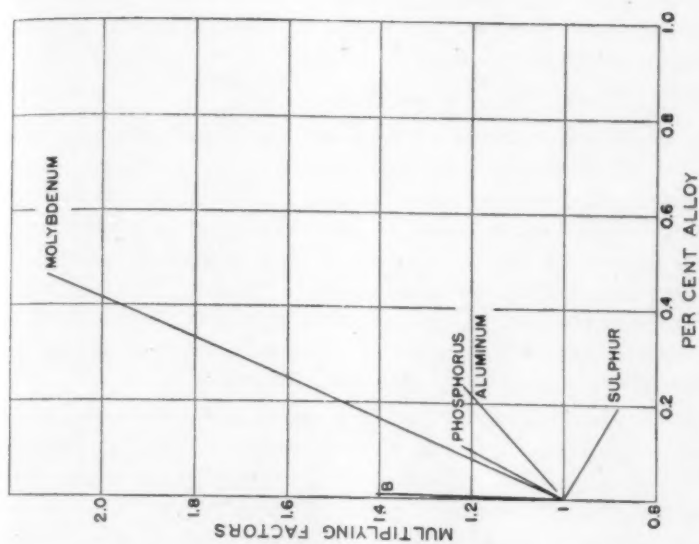


FIG. 15—HARDENABILITY OF MULTIPLYING FACTORS PLOTTED AGAINST PERCENTAGES OF VARIOUS ALLOYS.

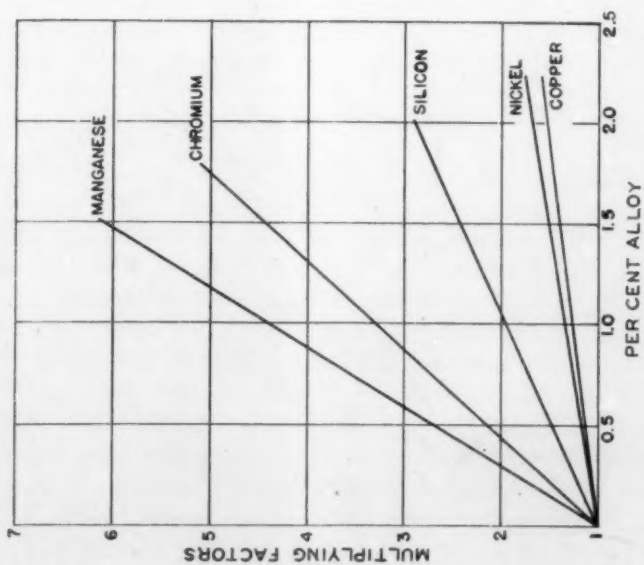


FIG. 14—HARDENABILITY MULTIPLYING FACTORS PLOTTED AGAINST PERCENTAGES OF VARIOUS ALLOYS.

out this study with the exception of the multiplying factors for molybdenum. A slight change in the factor curve for this element was made, which is believed to indicate more closely the effect of molybdenum on hardenability in the composition range in which it is most commonly used.

#### DISCUSSION OF RESULTS

39. The Jominy curves indicate good correlation between the hardenability of cast and forged steels having identical compositions when differences in grain size are considered. Therefore, it is believed that the hardenability factors established for forged steel also apply to cast steel when certain allowances are made for the presence of carbide formers. A study of the data shows that the lower carbon steels containing strong carbide forming elements, such as chromium and molybdenum, have measured hardenability values which more closely correspond with their calculated hardenability values than do the higher carbon steels of approximately the same alloy content.

40. This observation indicates that the tendency for such alloying elements to form insoluble carbides is increased as the carbon content is raised; thus, the ability of these elements to promote hardenability in the higher carbon steels is decreased unless relatively high quenching temperatures are used. Therefore, it appears obvious that larger amounts of strong carbide formers can be used more efficiently to promote hardenability in the lower carbon range than can be used in the higher carbon range.

41. Figure 16 illustrates the relation between calculated  $D_I$  and measured  $D_I$ . The correlation is extremely good in all cases except those where excessive quantities of stable carbide forming elements are present, and good correlation can not be expected in these cases since, as previously explained, the quenching temperature of 1650° F. (900° C.) was not sufficiently high to cause solution of all the carbides.

#### *Effect of Boron*

42. With the exception of those heats containing excessive amounts of elements forming stable carbides, the only steel covered in this investigation for which calculated hardenability does not agree reasonably well with experimentally determined hardenability is a steel (Heat N) which contains boron. The calculated hardenability of Heat S, another steel containing boron, agrees quite well with its experimentally determined hardenability. This apparent anomaly may be explained by the fact that Heat N was poured at a much higher temperature than was Heat S. Boron is thought to be readily oxidized at steelmaking temperatures<sup>13</sup>, and thus it is possible that the effect of boron on hardenability may be nullified when steel for castings is poured at the high temperature necessary to attain good fluidity.

43. This observation of the loss of the effect of boron on hardenability is confirmed by open-hearth shops where it has been noticed that there is a decrease in the hardenability from the first to the last ingot of steel heats con-

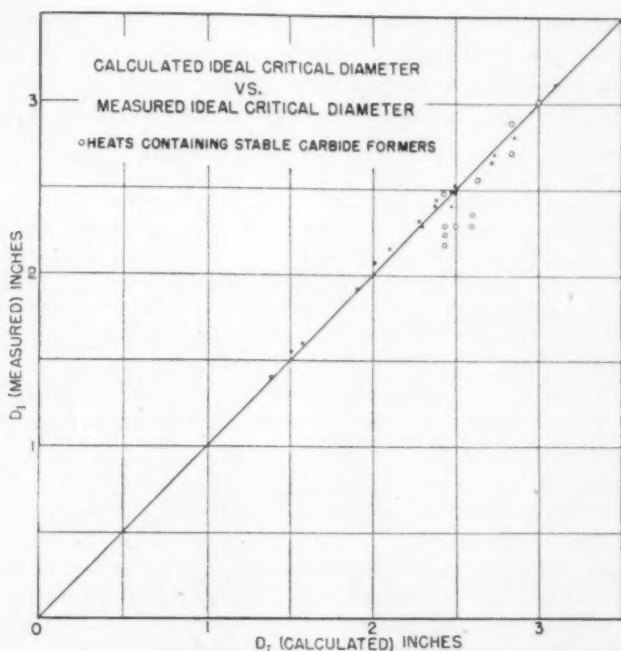


FIG. 16—CHART SHOWING RELATION BETWEEN CALCULATED AND MEASURED IDEAL CRITICAL DIAMETERS.

taining boron<sup>14</sup>. This "fading effect" has been attributed to the oxidation of the boron while the steel is in the ladle. Further, since boron is known to cause some coarsening of the austenitic grain (this is substantiated by the coarse grain size in Heat S), the moderate aluminum and the fine grain size of Heat N are further indications that the boron in this heat was oxidized.

#### CONCLUSIONS

44. For all practical purposes, cast steels may be said to have the same hardenability as forged steels of the same composition and grain size.

45. Within the range of composition of steels used in this study, normalizing treatments as high as 2000° F. (1090° C.) prior to quenching from 1650° F. (900° C.) do not materially affect the hardenability of cast steel except as they alter the as-quenched grain size.

46. Methods and factors applicable to the calculation of hardenability for wrought steels also apply to cast steels.

47. From these very limited observations on boron steels, it appears that boron can greatly increase the hardenability of cast steel. However, loss of effectiveness of the boron should be expected if high pouring temperatures are necessary.

48. When relatively high hardenability is desired in cast steel at the level of 0.35 to 0.45 per cent carbon, strong carbide formers, such as chromium

and molybdenum, should be held to limited quantities for reasons of economy; otherwise, their potential benefit to hardenability is not fully effective. At lower carbon levels, such as 0.15 to 0.25 per cent, increased amounts of such strong carbide formers can be used without sacrificing their full effect on hardenability.

### References

1. Vilella, J. R., Guellich, G. E., and Bain, E. C., "On Naming the Aggregate Constituents in Steel," TRANSACTIONS, A.S.M., vol. 24, pp. 225-261 (1936).
2. Clark, K. L., Bishop, H. F., and Taylor, H. F., "Heat Treatment of Medium Carbon Cast Steel in Moderately Heavy Sections," TRANSACTIONS, American Foundrymen's Association, vol. 51, pp. 617-646 (1944).
3. Grossmann, M. A., Asinow, M., and Urban, S. F., "Hardenability, Its Relation to Quenching, and Some Quantitative Data," A.S.M., HARDENABILITY OF ALLOY STEELS, 1939, p. 124.
4. Grossmann, M. A., "Hardenability Calculated from Chemical Composition," TRANSACTIONS, A.I.M.E., vol. 150, pp. 227-259 (1942), and METALS TECHNOLOGY, vol. 9, no. 1 (1942).
5. Shepherd, B. F., "The P-F Characteristics of Steel," TRANSACTIONS, A.S.M., vol. 22, pp. 979-1016 (1934).
6. Burns, J. L., Moore, T. L., and Archer, R. S., "Quantitative Hardenability," TRANSACTIONS, A.S.M., vol. 26, pp. 1-36 (1938).
7. Jominy, W. E., and Boegehold, A. L., "A Hardenability Test for Carburizing Steel," TRANSACTIONS, A.S.M., vol. 26, pp. 574-606 (1938).
8. Crafts, W., and Lamont, J. L., "The Effect of Some Alloying Elements on Hardenability," A.I.M.E. Technical Publication no. 1657, METALS TECHNOLOGY, vol. 11, no. 1 (1944).
9. Kramer, I. R., Hafner, R. H., and Toleman, S. L., "Effect of Sixteen Alloying Elements on Hardenability of Steel," A.I.M.E. Technical Publication no. 1636, METALS TECHNOLOGY, September 1943, vol. 10, no. 6.
10. Comstock, G. F., "The Effect of Titanium on the Hardenability of Steel," Report, Titanium Alloy Mfg. Co., Niagara Falls, N. Y.
11. Asinow, M., Craig and Grossmann, M. A., "Correlation Between Jominy Test and Quenched Round Bars," JOURNAL, Society of Automotive Engineers, p. 283 (1941).
12. Jackson, C. E., and Christenson, A. L., "The Effect of Quenching Temperature on the Results of the End-Quench Hardenability Test," A.I.M.E. Technical Publication no. 1647, METALS TECHNOLOGY, December 1943, vol. 10, no. 8.
13. Gurry, R. W., "The Relative Deoxidizing Power of Boron in Liquid Steel and the Elimination of Boron in the Open-Hearth Process," A.I.M.E. Technical Publication no. 1641, METALS TECHNOLOGY, December 1943, vol. 10, no. 8.
14. Proceedings of the National Open Hearth Committee, Iron and Steel Division, American Institute of Mining and Metallurgical Engineers, vol. 26, p. 192 (1943).



## DISCUSSION

*Presiding:* C. H. LORIG, Battelle Memorial Institute, Columbus, Ohio.

*Co-Chairman:* H. F. TAYLOR, Naval Research Lab., Anacostia Sta., Washington, D. C.

C. K. DONOH<sup>1</sup>: Were any hardenability tests made on bars that were not normalized?

MR. RICHARDS: Jominy bars were run on steels which had no normalizing treatment at all prior to quenching, and it was found that if corrected for grain size, there was no effect on hardenability. That statement might be qualified by saying that when excessive amounts of undissolved carbides were present in some cases there was a very slight improvement in hardenability.

The work on the effect of "prior-to-normalizing" solution treatments has not been carried far enough to advocate the complete abandonment of solution treatments, although it certainly points strongly in that direction.

J. B. CAINE<sup>2</sup>: There is one point regarding the solution treatment of chromium carbides. Have you used Field's\* curve for correlation between the end-quenched specimens and analysis?

MR. RICHARDS: No.

MR. CAINE: The only way I could correlate the work of Field and that of Grossmann\*\* was to use the lower limit of Grossmann's chromium range, and the particular bars that I used had been given a prior normalizing treatment at 1700° F. Perhaps a temperature of 1700° F. is not high enough, but the bars had been normalized and I still had to use the lower limit of this range of values. It would seem, then, that the solution of the chromium carbides is incomplete even at 1700° F.

MR. RICHARDS: What was your quenching temperature?

MR. CAINE: The quenching temperature was as given in the specifications, 60 to 75° F. above the critical point. The steels I tested ranged from 3.5 percent of nickel to 1010 steel, so that the quenching temperatures depended upon the analysis of the specimen.

MR. RICHARDS: It has been shown that different quenching temperatures do have an effect on the apparent hardenability of steels. The work of Jackson and Christenson showed that there is an effect of quenching temperature on the apparent hardenability of a steel as determined by the Jominy bar. A quenching temperature of 1650° F. was used throughout the investigation, and it did not prove to be sufficiently high for complete solution of all of the carbides.

R. E. KERR<sup>3</sup>: I wish to bring up the point that hardenability as such might not be the most important aspect of some water-quenched castings. At an A.S.M. meeting, Mr. Almen† stated that the tensile test is not indicative of the actual life of a casting, and he also stated that the long life service of some castings is due to compressional stresses set up on the exterior surfaces during quenching. He stated that the metallurgical structure obtained on quenching and tempering had nothing at all to do with the life of the part. To back it up, he stated a case of the Ford Motor Co., changing from an alloy part to a 1045 carbon-quenched steel, no tempering, simply shot blasted to produce compressional stresses on the exterior. He claimed that this quenched 1045 part gave them far better service than did those previously made from alloy steel.

MR. CAINE: Shot blasting, by creating compressive stress at the surface, does improve the fatigue strength of the part. This action, although important, has nothing to do with the physical properties or hardenability of the metal itself. Shot blasting a part that does not possess sufficient strength will not prevent failure in service.

\*<sup>1</sup> American Cast Iron Pipe Co., Birmingham, Ala.

<sup>2</sup>Sawbrook Steel Castings Co., Lockland, Ohio.

\*Field, J., "Calculation of Jominy End Quench Curves from Analysis," METAL PROGRESS, pp. 402-405, March, 1943.

\*\*Grossmann, M. A., "Hardenability Calculated from Chemical Composition," TRANSACTIONS, A.I.M.E., vol. 150, pp. 227-259 (1942).

<sup>3</sup>Pettibone Mulliken Corp., Chicago, Ill.

†General Motors Corp.

Mr. KERR: It was definitely stated that the metallurgical structure had nothing to do with the actual life of the part; that it was purely compressional stresses.

Mr. RICHARDS: I do not know whether it can be said definitely that the structure has nothing to do with the actual life of the part. We know that the structure does have a lot to do with the physical properties of a casting. Mr. Alman is referring to the Ford crankshaft, I believe, and the point brought out there is that strength and surface, and not necessarily ductility, are the requirements for a good crankshaft. The compression forces on the surface are very important to fatigue life. In a structurally homogenous section, cracks which lead to failure are started at the surface. If compressive stresses are induced at the surface by shot blasting or by peening, externally applied stresses must exceed the tensile strength of the material by a margin greater than the amount of compressive stresses introduced at the surface by shot blasting or peening in order to cause failure.

G. VENNERHOLM<sup>4</sup>: We believe that part of the success of the crankshaft is due to the very high damping qualities in this type of material. As for surface hardness, the crankshaft is not hard, for a fact has a rather low surface hardness.

In regard to shot blasting surfaces in order to improve fatigue life, considerable work has been done at the Ford Motor Company along these lines with very gratifying results. I believe that there is a parallel to this which may be of interest; namely, nitriding, which today is used quite extensively for the very purpose of improving fatigue life, through the high surface hardness produced by nitriding which results in very high compression stresses. It has been noticed that the fatigue failure, when such takes place, starts below the surface, that is, below the nitrided case rather than at the surface itself.

Lt. C. W. LUEDERS<sup>5</sup>: Mr. Richards, I understood you to say that a soft core, or at least not a very large soft core, is undesirable on a quenched casting.

Mr. RICHARDS: A soft core is undesirable if we want to develop the fullest physical properties, except in certain applications, such as might be expected in a gear.

Lt. LUEDERS: I would be a little more emphatic than you were, in that for certain well-known applications, it is important not to have the slightest bit of softness. We do not get the benefit of the hardenability to the fullest extent unless we harden it completely through, and if we correlate it with microstructure, it is quite surprising the effect that a very small amount of free ferrite has on physical properties. So it is misleading, perhaps, to consider that in general any softness at the core is desirable. Dr. Gensemer has done some very fine detailed work in correlating microstructure with physical properties on a quantitative basis. The curve for impact resistance versus percentage of free ferrite falls off very rapidly with the emergence of a very small percentage of free ferrite. So that for applications where we are depending upon maximum impact resistance it is important to harden completely through.

Mr. RICHARDS: As to Mr. Caine's question about the effect of segregation on hardenability and how it might affect the Jominy curve, a discontinuity in the Jominy curve which might be attributed to segregation has been noticed. This discontinuity can be minimized by solution treatments prior to quenching. The discontinuity near the quenched end of the bar appears to be predominantly controlled by carbon segregation, whereas discontinuities further from the quenched end of the bar appear to be controlled by alloy segregation. This evidence of segregation was not encountered in the present investigation, but should be considered when larger castings are to be quenched and tempered.

<sup>4</sup> Ford Motor Co., Dearborn, Mich.

<sup>5</sup> Office, Chief of Ordnance, Detroit, Mich.

## Observations on Industrial Safety and Occupational Disease Control

By JAS. R. ALLAN\*, CHICAGO, ILL.

### INTRODUCTION

1. Within the past year, the Industrial Hygiene Codes Committee of the American Foundrymen's Association drafted a code on "*Recommended Practices for Industrial Housekeeping and Sanitation*." This code covers recommendations for housekeeping, prohibits lunching in certain hazardous areas, prescribes general ventilation for work areas, offices, toilet, locker, rest and lunchrooms, and makes recommendations for minimum lighting requirements in factory, office and service areas.

2. The code also makes recommendations for the separation of potable water supply from other sources of water in the plant, and provides minimum standards for toilet room construction and the number of facilities for the employees. It also gives complete data on wash and locker room construction and specifies the minimum facilities required in proportion to the number of employees involved. Minimum requirements for women employees' restrooms are also prescribed. Factory lunchroom recommendations are also included.

3. This code was approved by the A.F.A. Board of Directors, for publication. It very nearly parallels a similar code that has been promulgated by the Illinois Industrial Commission and which, very shortly, will have the force and effect of law in that state.

### *Metal Cleaning Sanitation*

4. The American Foundrymen's Association "*Code of Recommended Good Practices for Metal Cleaning Sanitation*" is being sponsored with the American Standards Association with a view of having it become an American Standard. The work of the Sectional Committee of the American Standards Association is progressing on this code and, with some minor changes, the A.F.A. code probably will become a recommended American Standard. Members of the A.F.A. Industrial Hygiene Codes Committee have been active in several of the industrial states this past year, working with their respective labor departments or industrial commissions in connection with new industrial code material or revamping some of the states' existing codes.

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NOTE: This paper was presented at a Safety and Hygiene Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 27, 1944.

5. A situation has arisen in New York State—although it had been anticipated for some time—in connection with New York Department of Labor "Industrial Code Rule No. 10 Relating to Equipment, Maintenance and Sanitation of Foundries, and the Control of Dusts, Gases and Fumes in Foundries." This code became effective in New York State on February 1, 1942. Some members of the A.F.A. were on the advisory committee that helped to draft this code.

6. This particular New York code carries, under Part 2, Sec. 10-9.1.1, a requirement that the amount of dust in the breathing zone of an employee shall not exceed 30 million particles per cu. ft. of air in any foundry operation except that in abrasive blast cleaning rooms, concentration shall not exceed 10 million particles per cu. ft., assuming, of course, that such concentrations apply inside the fresh-air-supplied helmet or respirator that is worn by the operator.

7. The foundry members of the advisory committee that helped to draft these rules vigorously fought the injection of dust counts into the New York rules, but were overruled by the New York State Department of Labor. The practical men on the advisory committee saw that trouble would be encountered if such rules were adopted, and their predictions are coming true in this respect for the reason that Code Bulletin No. 10 not only specifies maximum dust concentration in the breathing zone but also provides a number of engineering rules for the control and elimination of dust at its source of generation. The two requirements are not compatible, and many of the foundries in the state now refuse to adopt any of the engineering rules specified in the code—they demand that the factory inspection division of the state prove that they are exceeding the 30-million dust count.

8. It appears that a complete breakdown of code rules for the state of New York is in prospect. This is a serious situation for the reason that long experience has indicated that good engineering safety rules can be complied with by the employer and afford ample protection against accidents and occupational disease. The Industrial Hygiene Codes Committee of the American Foundrymen's Association, as well as the Association itself, are against dust counts or maximum concentration of any toxic or hazardous material in any state code that has the force and effect of law, because they know from experience that the wisest and most satisfactory way of improving working conditions and eliminating exposure is to adhere to sound, reasonable engineering rules.

9. The foundry operators in the state of New York are urged to appeal, either directly or through the various trade associations, to the New York Department of Labor for the elimination of all so-called safe toxic limits from any code. This is extremely important for the reason that there is a contemplated revision of New York State Code Bulletin No. 12 which, at the present

state of revision, contains innumerable substances specifying so-called safe limits.

#### EQUIPMENT

10. A few pertinent observations, we believe, are in order at this time in connection with equipment, processes and working conditions in foundries and factories.

11. Many employers and operators of shops naturally have expanded their facilities and added a great deal of new equipment to take care of the tremendous increase in production for items that they were capable of producing. The equipment vendor, in many instances, has taken advantage of this situation in manufacturing and selling equipment with no regard for safety and health protection features. Many equipment vendors have taken the attitude of "take our equipment or leave it—other people will want it"—and they have not cooperated with the user and purchaser in supplying safe equipment, or even making it possible to apply safeguards and hooding to minimize exposures.

#### *Filters and Dust Collectors*

12. Then again, because of the tremendous demand for equipment of all kinds due to the manufacture of war products, there has been a great increase in the number of concerns manufacturing such equipment, and many of them have no knowledge of or experience in designing equipment that can be operated safely. A good case in point is the fact that many small concerns have started to build so-called unit type air filters or dust collectors attached to a piece of dust-generating equipment, such as emery wheel stands and the like, and these filters and collectors are of such design that after the air is passed through them it is recirculated back into the breathing zone of the employees. Most state laws, in such states where much thought has been given to the matter, are very strict in prohibiting recirculation of air that has been exhausted from a dangerous or hazardous operation.

13. Manufacturers and vendors of emery wheel grinding equipment for the most part fail to recognize accepted standards for the design and construction of the safety and ventilating hoods enclosing the grinding wheels. Manufacturers of such types of equipment have wasted a great deal of material in designing grinding wheel hoods that do not meet code requirements. The result is that such hoods have to be junked and the purchaser has to install hoods of his own design or, after a long battle with the vendor, obtain hoods that meet the minimum local requirements. It is not unusual to see a grinding wheel hood that requires a 4-in. inside diameter outlet to an exhaust pipe made with only a 2-in. or 2½-in. opening.

#### *Equipment Design*

14. There is, also, the vendor who supplies exhausting equipment for use with dust producing and generating equipment of which he is also the sup-



plier. Too often, the amount of ventilation, or in other words, the cubic feet of air to be exhausted per minute, is far below either the state requirements or what is generally accepted as good engineering practice. Here again there has been a waste of much strategic material and equipment that has been sold to the employers.

15. Of course, the average employer, during these busy days, has not had too much time to go into the engineering details of all the equipment that he buys and, in many instances, he does not have engineering staffs that are too well advised in such matters. As a result, the equipment vendor has taken advantage of the situation and sold purchasers many kinds of equipment that are not safe from an accident or health point of view.

16. There is a great need for cooperation between user, manufacturer and vendor of equipment for foundries and factories with a view toward building safe equipment. After the war, when there is more time, a strong campaign will be inaugurated to bring equipment vendors into line.

#### *Labor Turnover*

17. It is interesting to note that, due to the serious labor shortage at the present time, when workers can choose their places of employment, those departments, shops and other work places which have not done a very good job of providing a good working environment for their employees are experiencing great difficulty in obtaining help; generally, their labor turnover problem is very acute, and it appears that, notwithstanding the resistance of some employers to improve working conditions in their plants, and in spite of state laws and codes providing for safer places in which to work, the labor shortage is forcing employers generally to be more cognizant of their hazardous, dangerous or undesirable working conditions and to make some long-needed improvements.



## The Application of Local Exhaust Ventilation to Electric Melting Furnaces

By JOHN M. KANE\*, LOUISVILLE, KY.

### Abstract

*This paper describes a system of local exhaust ventilation that has proved feasible for electric melting furnaces in steel foundries. Positive exhaust of dust, fumes, and smoke is assured by preventing their dispersion to the melting room. Factors that influence the effectiveness of conventional general ventilation methods are also discussed.*

1. It has been conventional practice to remove smoke, dust, and fumes from electric melting furnaces by general ventilation through the use of roof monitors, ventilators and exhausters located in the roof trusses. Such systems, in spite of the use of very large exhaust volumes, may not prevent objectionable dispersion of the contaminants within the foundry, and may obstruct the vision of crane operators in the vicinity of the melting area.

2. There are several reasons why increased difficulty has been experienced in recent years with electric furnace ventilation:

- (1) New foundries have greater height than many older plants and have increased crane clearance. This increased height has increased the distance between the exhaust point and the furnace, and greatly increased exhaust volumes are required for comparable results.
- (2) Greater emphasis on plant cleanliness has resulted in a marked increase of exhaust ventilation and dust control systems throughout the foundry. These systems remove large volumes of air from the foundry. Where the make-up air supply\* is not adequate, a slight negative pressure in the building can occur and upset the general ventilation scheme for the melting room. Under extreme conditions, reverse air flow into the melting room area will be experienced due to the higher pressure characteristics of exhausters on other foundry exhaust systems.
- (3) The thermal efficiency of the electric melting furnace is high and, except during the boiling and certain refining stages, the temperature around the outside of the furnace is insufficient to

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produce a pronounced stack effect. This lack of marked difference between furnace and room temperatures largely accounts for the dispersing tendency of the smoke, dust and fumes, and explains why the smoke condition within the melting room varies so widely with atmospheric conditions.

3. Data shown in Fig. 1 were obtained by measuring the temperatures of

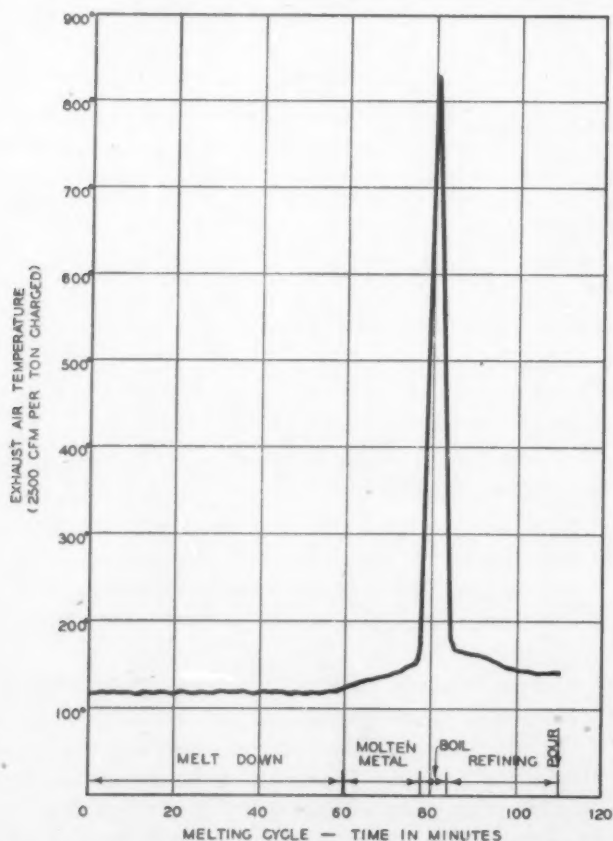


FIG. 1—TYPICAL TEMPERATURE RANGES OF EXHAUST AIR DURING MELTING CYCLE. LOW TEMPERATURES DURING MELT-DOWN AND MOLTEN-METAL PERIODS CAN PERMIT SMOKE DISPERSION DUE TO ABSENCE OF STACK EFFECT WHICH WOULD CAUSE SMOKE TO RISE RAPIDLY.

the exhaust air from a local hood mounted directly on the furnace roof ring. The furnace charge was 8,400 lb., and the exhaust volume of 10,000 cu. ft. per min. confined and exhausted all smoke, fumes and dust that normally would escape from the furnace. While similar charts for other furnaces show wide variations in exhaust air temperatures during boiling and refining, the same low temperature ranges always occur during the melt-down and molten-metal stages of the melting cycle. Unfortunately, the smoking characteristic

is most pronounced during the melt-down phase, at which time the stack effect from temperature differentials provides the least assistance to a system of general ventilation.

#### LOCAL EXHAUST VENTILATION

4. It has been long apparent that local exhaust ventilation would offer positive control of contaminants if exhaust hoods could be installed at the points of smoke generation—around charging doors, slagging doors, pouring spout and electrodes. Also, such a system would assure the required visibility for the crane operator. However, the application of local exhaust ventilation posed two problems that required extensive study:

- (1) A method of connection between the exhaust hood and a fixed exhaust duct that would permit the required furnace movement for charging, slagging and pouring. For top-charge furnaces, the swinging roof, coupled with the tilting motion for pouring and slagging, offered the greatest complications.
- (2) Exhaust hood design must assure accessibility to cooling glands, water connections and adjusting clamps, and ease of removal for roof repair or replacement.

5. Figures 2, 4, 5 and 6 illustrate a system of local exhaust ventilation that has proved effective and practical. Figure 3 shows the furnace in operation before local exhaust ventilation was applied.

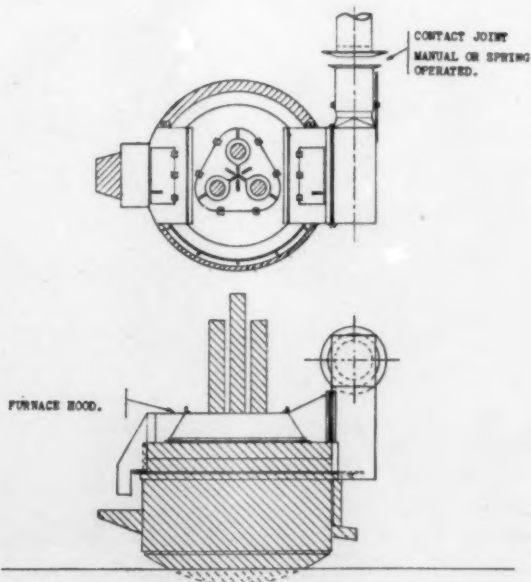


FIG. 2—SCHEMATIC DIAGRAM OF EXHAUST HOOD MOUNTED ON ELECTRIC FURNACE.

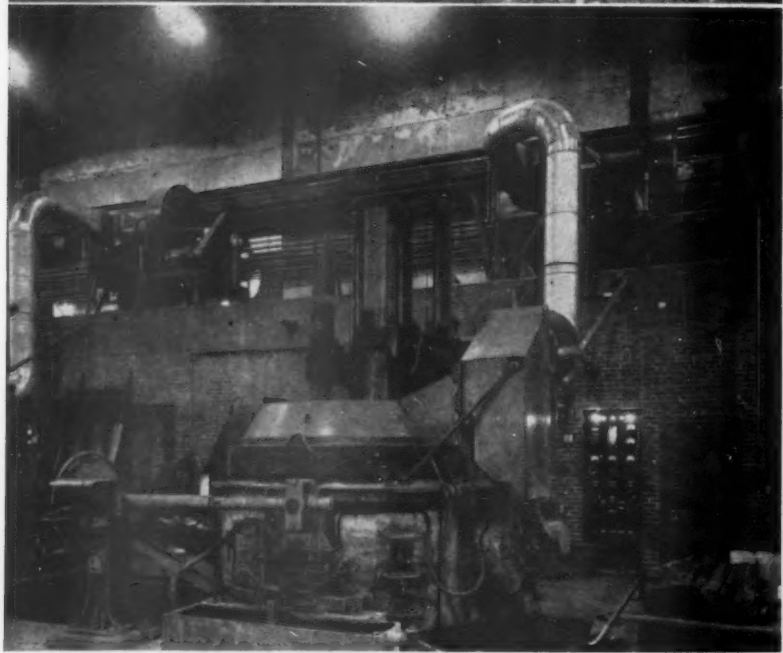


FIG. 3—TOP—AN ELECTRIC FURNACE IN OPERATION BEFORE INSTALLATION OF LOCAL EXHAUST VENTILATION.  
FIG. 4—BOTTOM—SAME FURNACE SHOWN IN FIG. 3 IN OPERATION WITH SYSTEM OF LOCAL EXHAUST VENTILATION.

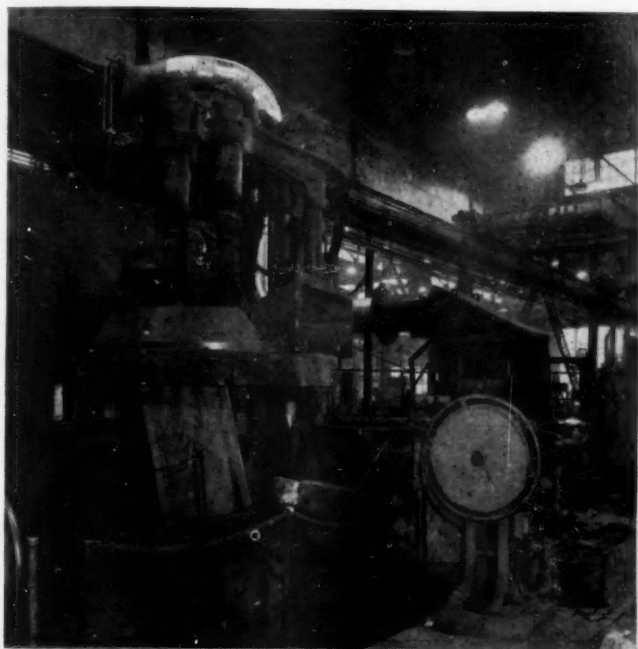


FIG. 5—TOP—FOR TOP-CHARGE FURNACES, ONE SECTION OF EXHAUST HOOD IS ATTACHED TO THE FURNACE ROOF RING AND MOVES WITH THE ROOF.

FIG. 6—BOTTOM—EXHAUST CONNECTION IS DISENGAGED WHEN FURNACE TILTS FOR SLAGGING OR POURING.

6. The exhaust hood, Figs. 2 and 4, consists of a plenum chamber design mounted on the furnace roof ring. For top-charge furnaces, the hood consists of two sections, a fixed section mounted over the slagging door, and a circular section that moves with the roof (Fig. 5). The two sections are not joined but, by careful construction and the use of flanged joints with labyrinth seals, leakage loss between the two sections represents but a small fraction of the total exhaust volume. Baffling within the hood proportions the exhaust volume to maintain the required indraft around the electrodes, and over the pouring spout and charging door.

7. During tilting for pouring or slagging (Fig. 6), the connection between the hood and the exhaust duct is disengaged unless a system of swivel and telescope joints is installed.

8. With local exhaust ventilation, the exhaust volume is a fraction of that required by general ventilation methods, as the contaminants are captured immediately at the point of escapement from the furnace and before dispersion can take place.

9. The use of a wet-type dust collector in connection with local exhaust hoods contributes to the effectiveness of such a system because:

- (1) The high temperature gases during boiling and refining are cooled to safe temperatures before passing through the air-moving equipment.
- (2) Contraction of the hotter gases by cooling assures almost the same volume of room air entering the furnace hood during the boiling and refining stage. This assures effective indraft to prevent smoke escapement during the entire furnace cycle.
- (3) Collection of a large percentage of fumes and dust becomes economically feasible and practical.

10. The use of local exhaust ventilation does not eliminate the need for general ventilation in the melting room. Smoke incident to pouring, alloying and ladle heating still must be exhausted, as well as some dust during the charging operation. However, with a system of local exhaust, the general ventilation capacity can be greatly reduced, and dispersion of smoke, dust and fumes during the melting cycle can be positively controlled.



## New Methods of Occupational Disease Control in the Foundry

BY WARREN A. COOK\*, CHICAGO, ILL.

### INTRODUCTION

1. New control methods for foundry health hazards include consideration of more effective control of hazards which have been long recognized and, also, of the handling of occupational disease conditions being more extensively introduced into foundries under present technological developments.

2. An occupational disease situation has the bad habit of remaining dormant over a period of time and then, like a volcano, with or without a warning, suddenly erupting with injury to those caught within its sphere. It is difficult, if not impossible, to predict and avoid damage from a new volcano; it is, also, often difficult but usually possible to predict and avoid injury from occupational diseases, even though certain of these may be new to many of us.

### INDUSTRIAL X-RAY EQUIPMENT

3. Consider the greatly increased introduction of industrial x-ray equipment for inspection of castings. Not only has there been a 2000 per cent increase in such use of this equipment over the past two years, but many of these x-ray units are of 1,000,000-volt capacity, with more recent development of units of twice this voltage.

4. Manufacturers of such equipment ordinarily may be depended upon to set up adequate precautions to prevent excessive radiation to operators and others in the vicinity. However, it is wise to ascertain definitely that protection is sufficient by using some of the instruments now available for checking the intensity of radiation which reaches employees adjacent to the unit, either directly or by rebound.

5. A case has occurred recently where inch-thick leaded glass was specified for adequate protection of the operator at the controls, but tests showed that more than the calculated quantity of rays penetrated into the control room. A measurement showed this leaded glass plate to be but  $\frac{1}{2}$ -in. thick, the error being ascribed to inexperienced installation men using what glass was available; both the manpower shortage and the material shortage under present

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war conditions contributing to the condition resulting in excessive exposure to the x-ray operator.

6. In the operation of x-ray equipment, there is further possibility of excessive x-ray radiation. Where castings are viewed by means of fluoroscopes, the operator may be protected by leaded glass plates and protective leaded rubber apron and gloves. With high power x-ray units of 500 and 1000 kilovolts in use, it is wise to view fluoroscopes by means of mirrors so that the operator can be assured of adequate protection by means of lead sheeting of the required thickness.

7. Today, portable x-ray equipment with lead-sheathed screens is transported by a crane to the location of the casting on the foundry floor. The convenience of such a portable unit is obvious, but not so obvious is the possibility of exposure to rays. The crane operator may be protected by distance, as the intensity of the rays decreases inversely with the square of the distance. However, the distance may not be so great but that the crane operator may be receiving more than the permissible daily dosage of a tenth roentgen. To play safe, the crane operator should be instructed to pull away from the area after lowering the equipment in place, or he should leave the crane cab.

8. Tables have been prepared giving the amount of radiation in roentgens, depending on the intensity of the source, the distance from the tube, thickness of lead or lead-glass protection, and time of exposure. Where the total daily exposure is less than a tenth roentgen, no injury from excessive x-ray radiation is to be expected.

9. Dependence usually is placed on these tables for assurance of proper protection but, as r-meters, counters, minometers and dosage meters become more generally available, the desirable practice of testing for integrated intensities of these rays at points where workmen or operators are stationed will become more of a usual practice, and desirably so.

10. The dosage meter<sup>1</sup> measures intensities of radiation either from x-ray or radium, as do most of these instruments. The scale range is from 0.0 to 0.2 roentgens per 8-hr. day, with the midscale value at 0.1 roentgens. The instrument is plugged into a 115-volt alternating-current line, is highly portable and can be set up at any point to check the radiation intensity.

11. The minometer<sup>2</sup> consists of an electrometer and an ionization chamber. This latter is in the shape of a fountain pen, and can be carried in the pocket of the exposed person. At the end of the day's operation, this chamber is placed in the electrometer for reading, the scale being calibrated for 0.0 to 0.1 roentgen. A larger chamber is also available for use with a 0.0 to 0.01 roentgen scale in the electrometer.

12. The National Bureau of Standards recommends that all industrial installations be checked thoroughly with a view to detecting radiation hazards

<sup>1</sup> Superior numbers refer to references at the end of the paper.

to personnel before the x-ray equipment goes into routine operation. Their handbook<sup>3</sup> should be referred to all operators, who should be thoroughly familiar with its provisions.

13. At the present time, the American Standards Association is developing an American War Standard for Protection in the Use of X-ray Equipment (Project Z-54). As soon as it is available, its provisions should be put into practice by every foundry operating industrial x-ray equipment.

#### FOUNDRY FUMES

14. Before discussing certain newer phases of the foundry dust situation, a number of special conditions which may confront the foundryman will first be reviewed. All of the items to which reference is made occur in no one foundry, but any of them may be introduced. Accordingly, it would be wise to know whether or not they are to be regarded with apprehension and whether precautions should be observed.

##### *Styrene*

15. Styrene usually is thought of as one of the polymers in synthetic rubber, but its use in some cases for impregnating magnesium castings is bringing this volatile liquid into the foundry. Toxicological data have been published concerning the health and flashfire hazards of this compound<sup>4-5-6</sup>. Its irritating properties tend to cause workers to avoid dangerous exposures. This cannot be depended upon as an infallible safeguard, as is evidenced by an instance where a worker in a pit where castings were being treated was rendered unconscious by the vapor. Fortunately, this man was removed from the exposure before any permanent injury occurred.

##### *Carbon Tetrachloride*

16. Core washes employing carbon tetrachloride as the suspending liquid had been discarded because of their health hazard, but have again come into use here and there. Excessive exposure to the carbon tetrachloride itself will cause injury to health and, in addition, the poisonous gas, phosgene, may be produced where the solvent comes in contact with hot castings or with sufficiently heated surfaces of the core oven.

##### *Cadmium*

17. A special warning should be issued in regard to cadmium. Fatal results may follow excessive exposure of only a few hours, or even less, to cadmium fume. This fume is highly irritating to the lungs, but cases are on record where the worker has stayed with the operation in spite of pulmonary distress—to be rewarded with a week or two in the hospital, if he does not succumb within 5 to 7 days after the exposure, as has happened in about 15 per cent of reported cases<sup>7</sup>.

18. Not only is there the possibility of poisoning where cadmium is used

in the preparation of an alloy in the foundry but, also, wherever cadmium dust or fumes may be produced by the grinding, burning or welding of cadmium-plated metals, cadmium alloys and metals covered with cadmium-bearing paint, excessive exposure is to be avoided, as is pointed out by the Ontario Division of Industrial Hygiene<sup>9</sup>. Purchasing agents and foremen should be informed about the dangers of cadmium poisoning, to guard as well as possible against the incidental introduction of cadmium into the plant with injury to workers before those charged with occupational disease prevention are aware of its presence.

### *Tellurium*

19. An alloying material which has been shown to be less of a health hazard than a social stigma is the metal, tellurium. When exhaust ventilation is inadequate to remove the fumes during melting and casting, a pungent garlic odor is imparted to the worker's breath. By the end of the day, the employe is shunned by everyone, from his fellow riders in the bus to his wife and children. In order to permit the worker to carry on his usual social contacts, it is essential that sufficient means be employed to reduce the exposure, as suggested by Steinberg<sup>9</sup>, whose researches demonstrated these metal fumes to be more obnoxious than poisonous. Steinberg cautions that concentrations in air be reduced by exhaust ventilation since his experiments were conducted on very low exposures and there is no information on the possible injurious effects of higher exposures. Automatic feeding devices for tellurium pellets and ventilated hoods at bull ladles are certainly in order.

### FOUNDRY DUST CONTROL

20. Much attention has been given by the foundry industry over the past dozen years to the control of dust. The industry is to be congratulated on the effective manner in which many of the excessive dust exposures, which formerly were taken for granted, have been handled. However, in both old and new foundries, unit operations continue to present problems which should be given further attention.

21. Among the unit operations on which much progress has been made are swing and stiff-leg grinders, sand conditioning equipment, and shake-out operations.

### *Grinders*

22. The present tendency in dust control for grinders is the provision of ventilated booths. Designs and air movement for representative installations were published recently by Kane<sup>10</sup>. Dust counts showing the exposure of the grinders at such ventilated booths in areas involving no other dusty operations have averaged as low as 1.8 million particles of dust per cu. ft. of air. In addition to such remarkably low dust concentrations, the job is noticeably cleaner and more attractive to the worker. Dust producing operations in the

vicinity of exhausted booths are to be avoided, as the ventilation at the booth will tend to draw such dust past the grinder operator into the exhaust system and unnecessarily increase his exposure.

23. Whether or not grinding operations, where the quartz percentage of the dust is low and total dust does not exceed five or ten million particles per cu. ft., actually causes injury to the lungs would seem to be exceedingly improbable on the basis of present information. Chest x-rays have shown some markings which simulate silicosis. There is a real possibility that these markings may be due to iron or iron oxide dust and, analogous to the harmless condition of welders' lungs resulting from iron oxide fume, may have no significance as far as injury to health is concerned. This question is of much interest to the foundry and the grinding wheel manufacturing industry, and should be made the subject of research.

#### *Sand Conditioning and Handling Equipment*

24. New sand conditioning equipment has been, to a large extent, provided with exhaust ventilation when installed. This includes enclosures with exhaust ventilation at sand mullers, ventilated hoods at points of sand transfer from down-spouts onto conveyor belts and from one belt to another, or to storage hoppers and bins, elevators, screens, mills and sand driers. The introduction of mechanized sand conditioning and handling equipment has brought additional problems, and the presence of a sheet metal enclosure and air mover should not be considered as proof that control is adequate.

25. At one well-ventilated sand conditioning operation in a new foundry, every dust producing area had been provided with enclosure and exhaust except the chute opening at the floor where such dry, powdery material as silica flour was dumped into the system. Although the operation was intermittent, it exposed the worker and others in the vicinity to high concentrations of fine quartz dust. This dust source was controlled by the provision of a housing about the floor opening sufficiently large to allow the worker to enter one end of it in dumping the bags of material. The exhaust duct entered the rectangular enclosure near the top of the end over the chute, so that the amount of material drawn into it would be minimized while allowing an adequate air movement through the open end and past the worker to reduce his exposure to this dust.

26. Where mechanical sand conditioning and handling equipment has been installed for several years, exhaust ventilation should be provided at areas of dust dissemination. Even though workers may not remain at many such points over extended periods of time, these areas distribute fine dust throughout the foundry and tend to raise general dust levels.

#### *Shake-Out Equipment*

27. The use of mechanical shake-outs has made provision of exhaust ventilation essential to control of the increased amounts of dust produced by such



operations. Such ventilating equipment is being very widely used, and it is the exception to find that exhaust ventilation has not been included.

28. The problem that still remains is the development of satisfactory means for dust control of shake-out grates for large castings which are handled hot from an overhead crane. Unfortunately, the hot casting constitutes an air mover of great capacity, and many an engineer has been disconcerted to observe his apparently well-designed and adequately ventilated side hood drawing in only a portion of the dust, the greater part of it shooting straight up past the influence of the exhaust ventilation. Here again research is needed, in this case to determine the air-moving capacity of hot masses of metal. Not only are convection air currents rising directly from the hot casting, but induced air currents are being pulled up with them, thus causing the observed interference with the satisfactory operation of the ventilated side hood. Whether the tight enclosure of the four sides of the shake-out grid from floor level to as high a level as permissible would greatly reduce the rush of induced air and so assist measurably in the solution of the problem, or whether some other approach could be made, can be best determined by experiment and research. The obvious but expensive method of doubling or quadrupling the amount of air exhausted might not be the only solution.

#### *General Foundry Ventilation*

29. Increased volumes of general ventilation have been introduced in many foundries. This seems to be most effective where the foundry is appreciably longer than it is wide, and provided with a high roof and low sides running the length of the foundry. In parts of the country where winter temperatures are low, it is necessary to provide heaters at air intakes along the low sides of the foundry building. The foremen of respective areas should be charged with the responsibility of keeping fans and heaters turned on and off, using individual switches for each fan and heater, depending on conditions in the foundry, if such a system is to be employed with any degree of economy.

30. Overhead skylights and propeller type exhaust fans have been used extensively to remove fumes from electric furnaces. The more recent provision of local exhaust, which has been adapted to the tilting furnaces, is far more satisfactory, as is discussed by Kane<sup>11</sup> in some detail.

31. Emphasis has been placed on equipment for the control of dust. A phase of dust control which cannot be overlooked in a completely successful program is that of the personal procedure of the workers as supervised by the foreman. A paper prepared for the foreman on this phase of dust control in the foundry has been published recently<sup>12</sup>.

32. Over the past few years of high wage levels, men have tended to continue at work rather than make claims for occupational disease. This has been especially true of silicosis. With the relatively small number of such claims, a number of foundrymen have become too complacent concerning the



hazards from excessive amounts of dust, and have brought themselves to the belief, on the basis of actual experience over these past few years, that the need for dust control was based on the "rocket" days of 1932 and 1933 rather than on any real hazard to the health of the worker or jeopardy to the financial reserves of the company.

33. It has been conclusively demonstrated by an extensive survey reported in 1938 by Greenburg<sup>13</sup> that increased dust exposures are associated with increased incidence of silicosis. The small minority of foundries which have continued operation during the period of high activity and long hours without giving attention to dust control on the basis of having had no silicosis claims over this period are laboring under a sense of false security. There is no question but that those concerns which have built dust control into their foundries will be well-rewarded for their good sense and sound policies by freedom from or the minimizing of claims for silicosis when pay envelopes begin to get thinner.

#### CONCLUSION

34. In conclusion, new methods of occupational disease control in the foundry depend, first, on the recognition and proper evaluation of the hazard; second, on the sincere intent of plant management to utilize practical and accepted measures for provision of a healthful workplace; third, on the installation of well-engineered ventilation and enclosures and an interest in research and the development of improved methods; fourth, on the supervision of foundry foreman over reduction of dust exposure on the part of the workers.

35. Much has been accomplished by the foundry industry but, in this matter of occupational disease control, it is not safe to become complacent and consider that the job has been completed. Continued vigilance is necessary to keep conditions as they should be. The reward of those concerns which maintain healthful and desirable working environments will be not only the absence of occupational disease, but the attraction of better grades of workers to their plants and an important influence for satisfactory industrial relations.

#### References

1. Dosage Meter, Geophysical Instrument Co., Key Blvd. and Nash St., Arlington, Va.
2. Minometer, Victoreen Instrument Co., 5806 Hough St., Cleveland, Ohio.
3. "X-ray Protection," National Bureau of Standards Handbook H.B. 20 (1936).
4. Spencer, H. C., Irish, D. D., Adams, E. M., and Rowe, V. K., "Response of Laboratory Animals to Monomeric Styrene." *JOURNAL OF INDUSTRIAL HYGIENE AND TOXICOLOGY*, vol. 24, pp. 295-301 (Dec. 1942).
5. "Allowable Concentration of Styrene Monomer," American War Standard Z37.15-1944, American Standards Association, New York.
6. Jones, G. W., Scott, G. S., and Miller, W. E., "Limits of Inflammability and Ignition Temperature of Styrene in Air." U. S. Bureau of Mines, Report of Investigations No. 3630, (March 1942).

7. Spolyar, L. W., Keppler, J. F., and Porter, H. G., "*Cadmium Poisoning in Industry: Report of Five Cases Including One Death.*" JOURNAL OF INDUSTRIAL HYGIENE AND TOXICOLOGY, vol. 26, pp. 232-240 (Sept. 1944).
8. CADMIUM POISONING EXPOSURES IN INDUSTRY, Division of Industrial Hygiene, Ontario Department of Health, Toronto, Canada.
9. Steinberg, H. H., Massari, S. C., Miner, A. C., and Rink, R., "*Industrial Exposure of Tellurium: Atmospheric Studies and Clinical Evaluation.*" JOURNAL OF INDUSTRIAL HYGIENE AND TOXICOLOGY, vol. 24, pp. 183-192 (Sept. 1942).
10. Kane, J. M., "*Dust Control for Swing Frame Grinders.*" THE FOUNDRY, vol. 72, p. 206, (August 1944).
11. Kane, J. M., "*The Application of Local Exhaust Ventilation to Electric Melting Furnaces.*" TRANSACTIONS, American Foundrymen's Association, vol. 52, pp. 1351-1356 (1944).
12. Cook, W. A., "*Industrial Dust Control.*" INDUSTRIAL SUPERVISOR, vol. 12, pp. 12-14 (October 1944).
13. Greenburg, L., "*Silicosis in the Foundry Industry.*" Reprint No. 38-35, Management Series No. 5—1938, American Foundrymen's Association, Chicago, Ill.

## Toxicity of Fumes Generated in the Operation of Electric Furnaces

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1. Very little material has been recorded on the composition and hazards of the fumes given off from electric furnaces.

2. Four cases of subacute and chronic mercury poisoning, with one death, were reported by Jordan and Barrows<sup>1</sup> in England in 1924 among workers at high-frequency furnaces. The mercury escaped from converters, and the mercury content of the surrounding air was about 0.7 milligram per cubic meter.

### SILICON ALLOYS

3. In 1937, attention was called to a potential silicosis hazard in the electric-furnace production of silicon alloys<sup>2</sup>. Silicosis cases were reported from two plants in Sweden, where the workers were exposed to silica smoke arising from the electric furnaces making silicon alloys. The dust was described as a finely divided powder containing 89 per cent free silica. In one plant, it took 4 yr. of exposure to develop an early case, while 14 yr. were required in the other plant. This difference in exposure time was credited to the inefficient exhaust system in use in the first plant for controlling the generated fumes given off from the furnaces.

4. The industrial health section of the company with which the author is connected made an exhaustive study at two plants of one of the largest producers of silicon alloys in the United States, immediately after the publication of the Swedish report. Periodic rechecks have been made since the first study in 1937.

### *Electric Furnace Operation*

5. A combination of resistance and arc-heating is used in the electric-furnace production of silicon alloys. These furnaces usually are of the open-pot type, with several large carbon electrodes projecting down into the charge. The current passes from the electrodes through the charge to the shell of the pot. The heat generated by the arc, plus that developed by the resistance of the charge, melts down the materials to form the alloy.

6. The operating floor is level with the top of the open-pot furnace. The

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<sup>1</sup> Superior numbers refer to references at the end of this paper.

carbon electrodes are adjusted and replaced from platforms, called intermediate floors, over the furnace. The ends of the electrodes are tapped and threaded so that new sections can be added as required. Work on the electrode platform is seldom carried on while the furnace is in operation. The electrodes are regulated from the operating floor. Raw materials are delivered by a high-line conveyor and dropped through chutes to the operating floor. These materials are hand-shoveled from the floor into the furnace.

7. The tapping of the furnace is done in practically the same manner as in tapping an open-hearth furnace. Slag is tapped off first, and then the metal is run out into sand molds on the floor. The slag and metal tap holes are plugged with clay.

8. In the charging and operation of the furnace, the workmen are engaged in heavy manual labor and exposed to excessive heat, radiant energy and the fumes and dusts given off by the furnace reactions. In many instances, no attempt is made to entrap the generated dust and fumes and to vent them to the outside atmosphere. Due to the heat generated in the furnace, the fumes and dusts tend to rise vertically. The roof of the furnace room is necessarily high in order to accommodate the electrodes and the raw materials high line. A monitor-type roof, skylights or vents allow the dust and fumes access to the outside atmosphere. There is an accumulation of settled dust on every horizontal surface under the roof. The greatest exposure to these arising dusts and fumes is at the high-line conveyor or mixing runway level. A few men are stationed on this level to divert the raw materials to the chutes feeding the furnaces. Recently, mechanical controls have been installed so that one man can take care of all furnace raw materials supply chutes from a central station. This station is located in a separate room, with a fresh air supply from an uncontaminated source. The workers on the operating floor are exposed to the lowest dust and fume concentrations. Only at the time of tapping the furnace do the fume concentrations increase and, in some cases, exhausts have been applied at the tap hole of the furnace to control them.

9. Any abnormality of furnace operation, such as a boil or pop, necessarily increases the evolution of dust and fume.

#### *Cooling Fans*

10. Large blower cooling fans are used on the operating platforms, especially during the summer months. Tests have shown that these fans are, at times, the cause of increasing the dust and fume concentrations at certain operating stations. This was found to be especially true when tapping the furnace. Higher concentrations also were found during the operation of furnace cleaning. Enclosing the furnaces and venting through a stack to the outside atmosphere materially reduced dust and fume concentrations at all working stations. Under such control, the gases are burned at the top of the stack.

11. In the production of ferrosilicon, the furnace charge consists of coke, quartzite and steel turnings. The quartzite, in large lumps, is washed and free of fines before delivery to the furnace building. The products of reaction are carbon dioxide, carbon monoxide, ferric oxide, and fine silica dust.

12. Tests for carbon monoxide ranged from zero to 35 parts per million on the operating floor and on the tapping platform, but concentrations of 60 to 80 parts per million were found at the high-line level. Concentrations at the intermediate floor stations vary greatly, in most instances being too high for continuous exposure.

#### *Silica Dust*

13. The silica dust is of an amorphous nature, and appears to be in the form of small globules of one micron and under in diameter. Visually, the dust concentrations appear to be very heavy. The small diameters of these particles may account for the relatively low dust counts found by the standard technique of the U. S. Public Health Service, namely, sampling with a Greenburg-Smith impinger and standard light field counting technique. No appreciable difference in counts was noted between using ethyl alcohol and water as entrapping mediums, thus ruling out the solubility of these small particles.

14. Typical dust concentrations determined at representative working stations at both an open type and an exhausted furnace producing ferrosilicon are as follows:

<i>Working Station</i>	<i>—Dust Concentration,—</i>	
	<i>Million particles per cu. ft. air</i>	
	<i>Open-Type Furnace</i>	<i>Exhausted Furnace</i>
On high conveyor line above furnace	158	86
On tapping platform while tapping	63.6	28.2
On working platform	75 to 178	21

15. Tests taken in an air-supplied cabinet on the high conveyor line showed an average concentration of 3.7 million particles per cu. ft. of air. This is equal to the average concentrations found on city streets. The disadvantage of the cabinet is the high temperature, especially in the summer months, which cannot be overcome by air motion. A means of cooling the supplied air is being considered.

16. The settled dust above the ferrosilicon furnaces contains 29.2 per cent of carbon and 53.58 per cent of silica. As previously stated, this silica is in the amorphous state. Studies of the effects from the inhalation of silica dust have been confined almost entirely to the crystalline variety of silica, and its hazardous qualities have been well established. When we speak of lung fibrosis, known as silicosis, and its relationship to tuberculosis, we refer to the effects of the inhalation of crystalline silica. While certain animals have been exposed to amorphous silica, sufficient work has not been done to definitely define its

effects, and it is not always possible to translate effects on animals into analogies on human beings.

17. An examination of x-ray films of workers exposed to diatomaceous earth (composed of 85 per cent or more of amorphous silica) indicates the presence of a fibrosis in certain workers who have been exposed over a period of years. However, this fibrosis is not a typical fibrosis which is recognized as silicosis. In the few cases the author has seen, there is an absence of the typical nodulation associated with silicosis.

18. In the plant surveyed, x-ray films of the chest are taken of certain employees on occasion, and an opportunity was afforded to review some of these. Three were of particular interest, because they were films of workers who had been exposed to ferrosilicon furnace dust over a period of 25 years or longer. Two of these exhibited normal chest shadows, and the third gave evidence of a mild, non-incapacitating fibrosis suggestive of an old secondary infection. No nodular fibrosis suggestive of silicosis was observed in the films reviewed. The investigators were thus unable to confirm the findings observed in the study from Sweden. It is the author's opinion that the silica smoke is in such a fine state of subdivision that the particles inhaled are as readily exhaled, or are rapidly eliminated from the body.

19. These conclusions were later modified on findings of the U. S. Public Health Service that, on interperitoneal injection of this dust into animals, a combined reaction that is inert and proliferative was produced. They reported that dusts producing this type of reaction should be considered potentially harmful.

20. In 1935, Gardner<sup>3</sup>, reporting on the injections of dusts into animals, stated that opal, an amorphous variety of quartz, produces tissue reactions similar to those of crystalline silica.

#### CHROMIUM ALLOYS

21. In the production of ferrochrome, the work is carried out in smaller, single-phase furnaces. The charge consists of chrome ore and coke. The melt is tapped into clay-lined pots, allowed to settle, and the metal tapped from the bottom. The lighter slag remains in the pot. Carbon was reduced in some of the melts by blowing in Bessemer converters with oxygen.

22. The following figures are typical of conditions found at these furnaces:

Location	Dust Concentration,		Remarks
	million particles per cu. ft. of air	Chrome, milligrams per 8-hr. day	
On working platform	44.6	8.2	Furnace not exhausted.
On working platform	8.2	3.5	Furnace exhausted.
In crane cab over furnaces	9.1		Over all furnaces.

23. Very little is known regarding the toxicity of chromium in the metallic form and, as such, it generally is considered inert.



## MANGANESE ALLOYS

24. In the production of ferromanganese, there is a different story, as both the dusts and the metallic fumes of manganese ores are toxic. The allowable maximum exposure is 60 milligrams per 10 cubic meters of air. Ten cubic meters of air would be the average normal amount breathed per work day by a man at moderate labor.

25. Studies made at enclosed exhausted, and enclosed but not exhausted furnaces showed the following dust concentrations:

<i>Location</i>	<i>Dust Concentration, million particles per cu. ft. of air</i>	<i>Manganese, milligrams per 10 cu. meters</i>	<i>Type of Furnace</i>
Operating floor	10.0	5.3	Enclosed, not exhausted.
Operating floor	7.9	3.8	Enclosed and exhausted.
Mixing runway above furnaces	231.1	132.7	
Furnace intermediate floor		23.0	Enclosed, not exhausted.
Furnace intermediate floor		1.9	Enclosed and exhausted.

26. The settled dust on rafters in this furnace building showed the following percentages of free silica and manganese:

<i>Location</i>	<i>Free Silica, per cent</i>	<i>Manganese, per cent</i>
Mixing runway	31.0	32.0
Intermediate floor, furnace not exhausted	25.6	25.8
Intermediate floor, furnace exhausted	44.2	0.6

27. These results definitely show that a safe manganese concentration can be maintained in the furnace room atmosphere by properly enclosing and exhausting the furnace fumes and gases to the outside atmosphere. Natural draft exhaust or chimney effect was used on the furnaces mentioned in the foregoing findings.

## OTHER ALLOYING ELEMENTS

28. Too few studies have been made on the production of tungsten, cobalt and ferrovanadium to report at this time. Very little is known about the toxicities of cobalt and tungsten. Tungsten has been determined by animal experimentation to be a slow poison and asphyxiant and probably capable of cumulative and chronic effects, but, despite wide use in industry, to the author's knowledge no occupational cases have been reported. Vanadium is a metallic poison about which little is known. German authorities report that it is irritating to the respiratory tract, and that it is, also, a systemic poison of a serious type. Reports of cases in industry in this country have been rare and have not been thoroughly confirmed. Two cases of vanadium poisoning developing on short exposure to vanadium ore dust have been reported. The cases developed symptoms similar to those of pneumonia and resulted in hospitalization for two weeks.

29. A survey of an electric steel plant engaged in the manufacture of alloy

steels in the form of rods, strips and wire, provided an opportunity to sample the fumes given off from smaller-type furnaces. The alloy steels were made in small batches, and the alloying metals were weighed out and added just before the heat was ready to be tapped.

30. Air samples taken on the operating platform showed 0.042 milligrams of manganese per 10 cubic meters of air, but negative for tungsten. These were the two alloys used in the melts at the time of the survey. Chromium, vanadian, nickel, and selenium also were used at various times in making alloy steels. Samples of settled dust analyzed as follows:

Location	Per Cent						
	Cr	Mn	V	W	Se	Ni	Co
Melting floor	3.38	0.428	0.011	0.0	0.0	0.079	2.31

31. An electric furnace department of one of the large steel companies producing alloyed steels has been surveyed a number of times during the past 8 years. This department comprised four electrode and one induction-type furnaces. No means of entrapping and removing the generated fumes and gases are provided. The furnace room has a high ceiling with a monitor-type roof which allows the escape of some of the arising dusts and fumes. A crane runway provides a means of charging the furnaces and the handling of the ladles.

32. The following results are typical of the concentrations found in this department at representative operating stations:

Location	Dust Concentrations, milligrams per 10 cu. meters of air			
	Mn	Mo	Cr	
Pouring floor	0.529	0.247	Trace	Less than 0.0003 mg.
Charging door of furnace	2.507	1.341	Trace	
Between two furnaces	0.777	0.706	Trace	
Crane cab	14.124	1.694	Trace	

33. Tests at the foregoing locations for oxides of nitrogen, fluorides, and carbon monoxide were negative. A sample of rafter dust collected on the crane operating over these furnaces showed the following composition:

	Per Cent
Loss on ignition	7.35
Total silica	9.44
Iron and alumina	24.08
Calcium oxide	36.54
Chromium	0.15

34. Tests for lead, silver, mercury, copper, cadmium, zinc, arsenic, antimony, tin, selenium, nickel, strontium, barium, bismuth, and cobalt were negative.

## CONCLUSIONS

35. In general, no conclusive evidence is hereby presented of the harmfulness of the fumes given off in electric furnace production of ferro alloys and steels, with the exception of those in the production of ferromanganese.

36. There is not sufficient x-ray evidence available to determine the toxicity of the amorphous silica fumes. However, animal injection does show that caution should be exercised in exposing workmen to heavy concentrations for long periods of time.

37. There are conditions when and where the concentrations of carbon monoxide may become hazardous for continuous exposure, and concentrations which may cause headaches often are present on the mixing conveyor or high line.

38. The dusts and fumes often present a safety hazard in obstructing vision, and are a definite nuisance.

39. The highest concentrations naturally are found at locations above the operating floor of the furnaces, where the fewest number of employees are working.

40. If the generated dusts should be classified as inert, the concentrations found are too high for continuous exposure, as is prescribed by code in some states.

41. The hooding and venting of the generated fumes and gases to the outside atmosphere are recommended as a safety precaution and, also, to prevent the deterioration of operating machinery, as for instance, motors. The efficiency of such a procedure has been demonstrated.

## References

1. "Occupation and Health," International Labour Office, Brochure no. 191, Iron, Pig Iron and Steel Industries, Geneva, 1930.
2. Bruce, Torsten, "The Occurrence of Silicosis in the Manufacture of Silicon Alloys," JOURNAL OF INDUSTRIAL HYGIENE, vol. 19, no. 4, April, 1937, pp. 155-162.
3. The 1935 Annual Report of the Saranac Laboratory for the Study of Tuberculosis, p. 8.

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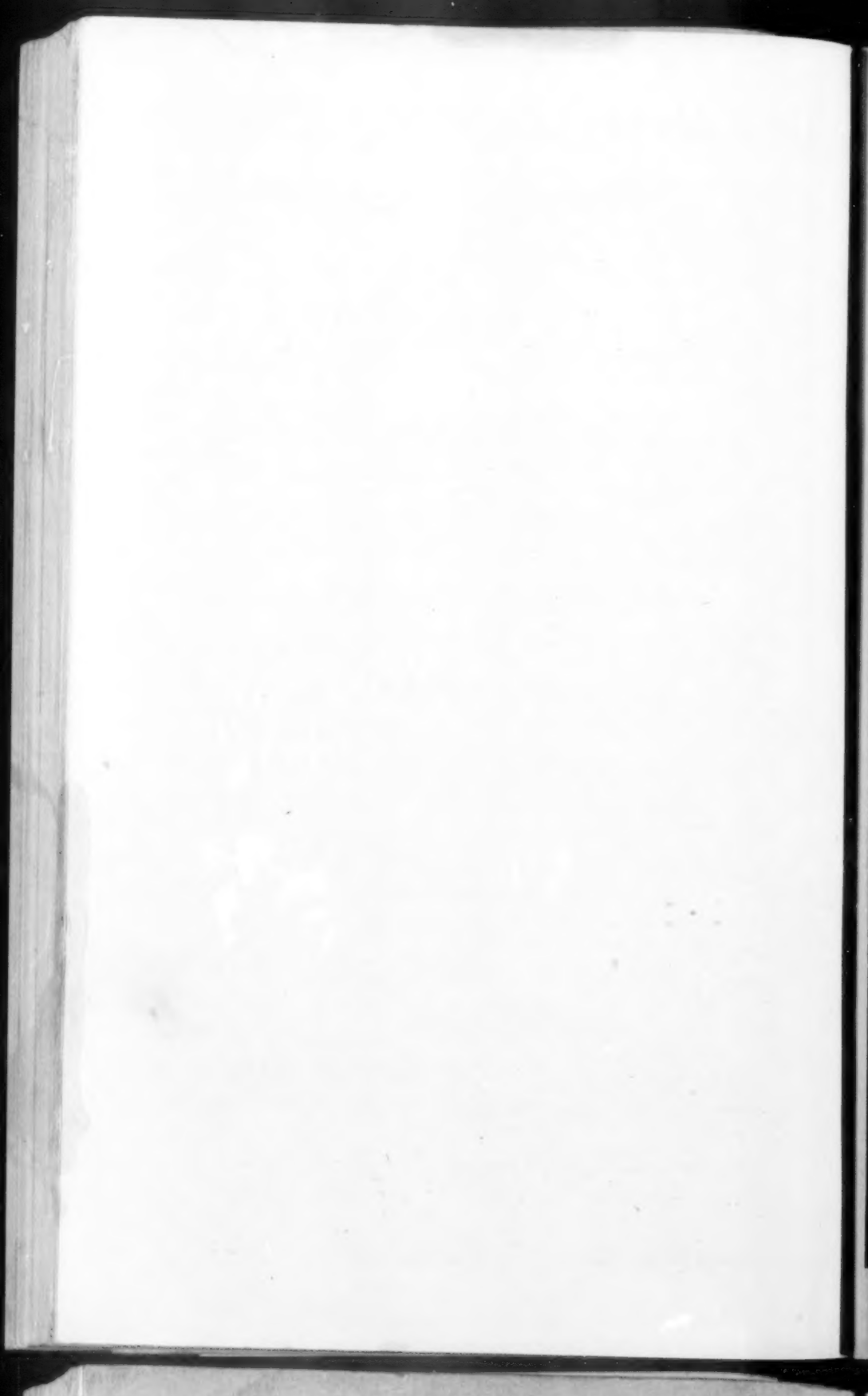
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